AU/AFFELLOW/2001-04

AIR FORCE FELLOWS PROGRAM

AIR UNIVERSITY

PRECISION ENGAGEMENT
AT THE STRATEGIC LEVEL OF WAR:

GUIDING PROMISE OR WISHFUL THINKING?

by

Timothy J. Sakulich, Lt Col, USAF

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

Maxwell AFB, Alabama

April 2001

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
01APR2001	N/A	-

Title and Subtitle Precision Engagement at the Strategic Level of War: Guiding Promise or Wishful Thinking?	**Contract Number**
	Grant Number
	Program Element Number
Author(s) Sakulich, Timothy J.	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Air University Maxwell AFB, AL	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 79	

Disclaimer

Contents

Illustrations

Preface

At least for the U.S. military, precision aerospace capabilities appear to have become the *sine qua non* for applying force in the defense of national interests. Consequently, airmen have an obligation to study the relationship between precision and warfare. This paper examines a key doctrinal assertion about that relationship, and I hope it generates a lively discussion that ultimately strengthens aerospace doctrine and its influence over future military strategies.

I would like to thank Dr. Philippe Loustaunau at the Institute for Defense Analysis (IDA) for his friendship, support and encouragement as an informal advisor in the development of this paper. His probing questions, expertise and our spirited conversations over the nearest white board ultimately helped me develop my own ideas more effectively. I would also like to thank Mr. Michael Leonard, the Director of IDA's Strategy, Forces and Resources Division (SF&RD), for sponsoring this fellowship opportunity and for providing an outstanding environment in which to do this research. He and his staff made this fellowship experience highly rewarding by inviting me to participate in other studies and graciously including me in on division social activities.

Most of all, I thank my wife Diane. Despite being a full-time mom to our twelve-, nine- and five-year-old children, and despite having carried and delivered beautiful twin girls in February, she still found time to discuss this research, review drafts and generally provide unwavering support and encouragement to me. She is a remarkable woman.

Abstract

Air Force Basic Doctrine asserts that the precise application of force can reliably generate desired, discriminate effects at the strategic level of war. A deconstruction of that assertion reveals three necessary assumptions: the ability to clearly define desired discriminate effects at the strategic level of war, the ability to trace the desired discriminate effects back to a triggering action, and the ability to ensure that the actual effects generated by the triggering action are only the discriminate ones being sought.

This paper presents evidence that these assumptions suffer from important conceptual weaknesses that are amplified when examined from the perspective of nonlinear and complex systems. Further evidence suggests that technological fixes are not likely to resolve these weaknesses nor produce the strategic efficiencies implied by the doctrinal concept. In fact, such fixes could increase the potential for small errors to combine in unexpected ways to create a system accident, where outcomes diverge in significant and undesirable ways from the intended discriminate strategic effect.

This paper cautions against using the term "precision" in ways that imply congruency between technology and war, and recommends that doctrine clearly differentiate technical exactness from strategic correctness. It concludes that effect-based approaches can foreclose adversary option sets with far more reliability than compelling specific, predetermined behaviors. And, it emphasizes the need to ensure that adaptation remains a fundamental feature of any effects-based concept.

Chapter 1

Introduction

> *[The] art of commanding aerospace power lies in integrating systems to produce the exact effects the nation needs.*[1]
>
> —AF Vision 2020

In his book, *Technology and War,* distinguished military historian and author Martin Van Crevald discusses the tight interrelationship between war and technology: "war is permeated by technology to the point that every single element is either governed by or at least linked to it. …it is no less true that every part of technology affects war."[2] This relationship is particularly acute for airman as a result of what John S. Foster and former Air Force Chief of Staff General (Ret.) Larry D. Welch call a revolution in precision that permeates weapons, navigation, surveillance, and command and control.[3] The integration of precision technologies into aerospace systems has enabled order-of-magnitude improvements in combat efficiency (i.e., combat aircraft losses, tonnage per target, and overall combat losses).[4] Not surprisingly, precision technologies have greatly influenced the airman's view of war, and *Air Force Basic Doctrine* embraces precision in part because it increases the efficiency of aerospace force application.[5]

But AFDD 1 goes much further when it asserts that the precise application of force can reliably generate desired, discriminate effects at the strategic level of war. In doing so, AFDD 1 extends the role of precision well beyond quantitative and engineering

measures of efficiency, and beyond an earnest desire to limit collateral damage. AFDD 1 in fact implies something far more fundamental about the nature of war. This paper examines whether it is reasonable to build a war fighting concept around such an idea, henceforth referred to as *strategic precision engagement*.

Doctrine appears to be in conflict with itself on this matter. AFDD 1 asserts that "war is a complex and chaotic human endeavor. Human frailty and irrationality shape war's nature. Uncertainty and unpredictability—what many call the 'fog' of war—combine with danger, physical stress, and human fallibility to produce 'friction,' a phenomenon that makes apparently simple operations unexpectedly, and sometimes even insurmountably, difficult. Uncertainty, unpredictability, and unreliability are always present."[6] The juxtaposition in doctrine—of a core competency of airpower built around precision application of force seeking discriminate outcomes at the strategic level of war on the one hand, versus Clausewitzian friction on the other—appears contradictory.

Doctrinal contradictions matter because doctrine is supposed to represent "a statement of officially sanctioned beliefs….a common set of understandings on which airmen base their decisions."[7] Moreover, doctrine's influence is not confined to the aerospace professional but ultimately affects national strategic choices. As Barry Posen puts it, doctrine "is the subcomponent of grand strategy that deals explicitly with military means."[8] Yet despite the potential significance of the internal conflict, it may not be possible to fully resolve it and it is not the goal of this paper to attempt to do so. Instead, the author embraces Michael Handel's perceptive conclusion that tensions and contradictions are inherent in military theory and doctrine. In his book, *Masters of* War, he argues that "the strategist's objective is not necessarily to resolve or eliminate every

anomaly, but rather to understand why wrestling with these questions can bring better insight into the nature of war."[9]

This author's wrestling with the idea of strategic precision engagement has revealed three *necessary* assumptions underlying the concept: the ability to clearly define desired discriminate effects at the strategic level of war, the ability to trace the desired discriminate effects back to a triggering action, and the ability to ensure the *actual* effects generated by that action are only the discriminate ones being sought. Yet there is evidence that these key assumptions suffer from important conceptual weaknesses. These weaknesses are amplified when the problem is examined from the perspective of nonlinear and complex systems. Further evidence suggests that technological "fixes" are not likely to eliminate the weaknesses, nor are they likely to produce the strategic efficiencies implied by the concept. On the contrary, such fixes will tend to increase the potential for "system accidents," where small errors combine in unexpected ways to create disproportionate and even disastrous strategic consequences. The "solution" is for doctrine to clearly differentiate between technical exactness and strategic correctness; recognize that foreclosing adversary option sets is more reliable than compelling specific, predetermined behaviors; and emphasize adaptation in effects-based concepts.

To lay out the research findings, chapter 2 explores how USAF doctrine connects precision engagement to the strategic level of war. Chapter 3 deconstructs that relationship to reveal key assumptions; chapter 4 explores the problem using insights from the study of nonlinear and complex adaptive systems; chapter 5 assesses the potential for a technological solution; and chapter 6 offers conclusions and proposes ways to avoid the pitfalls inherent in strategic precision engagement.

Notes

[1] US Department of the Air Force, *Global Vigilance Reach & Power: America's Air Force Vision 2020*, 4.

[2] Martin Van Crevald, *Technology and War: From 2000 B.C. to the Present* (New York: The Free Press, 1989), 311.

[3] John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today,* December 2000, 31.

[4] Maj Gen John Barry, director of strategic planning, US Air Force, address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 7 February 2001. Briefing slides available on-line from http://www.aerospacepower.org/Conference Briefings/Intro – Maj Gen Barry.ppt.

[5] Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine,* 1 September 1997, 16.

[6] Ibid, 6.

[7] AFDD 1, 1. Military expert Trevor Dupuy defines doctrine as "the combination of principles, policies and concepts into an integrated system for the purpose of governing all components of a military force in combat, and assuring consistent, coordinated employment of these (military) components….Doctrine represents the available thought on the employment of forces that has been adopted by an armed force." Trevor Dupuy, "Theory of Combat," in *Brassey's Encyclopedia of Military History and Biography, eds. Franklin D. Margiotta et al.* (Washington, D.C.: Brassey's, 1994), 975.

[8] Barry R. Posen, *The Sources of Military Doctrine* (Ithaca, NY: Cornell University Press, 1984), 13.

[9] Michael I. Handel, *Masters of War: Classical Strategic Thought, 2nd Ed.* (London: Frank Cass., 1996), 6.

Chapter 2

Aerospace Precision and Strategic Precision Engagement

> *Above all, PGMs connect political objectives to military execution with much greater reliability than ever before. The political leader can have far greater confidence that discrete objectives can be met and can thus gain broader latitude in formulating the overall objective. This is not just a change in air power or even in military power; it is a fundamental change in warfare.*[1]
>
> —General Charles Boyd

Air Force Basic Doctrine notes that "precision has been an integral aspect of air strategy since the advent of daylight bombing doctrine in the 1930s."[2] This chapter describes how current USAF doctrine relates precision capabilities to discriminate strategic effects. It begins by highlighting aerospace precision in terms of quantitative and engineering measures of efficiency, then describes how doctrine extends precision engagement to the strategic level of war.

Precision and Aerospace "Efficiencies"

It is clear that precision technologies have allowed airpower to achieve unprecedented efficiencies in the application of raw combat power. For example, during the execution of the Combined Bomber Offensive, it took 3000 sorties dropping 9000 bombs with a circular error probable of 3000 feet to destroy a 60-by-100 foot target.[3] Today, the same target can be obliterated with a single precision guided weapon

delivered by a Joint Direct Attack Munition (JDAM) delivered by a single B-2A sortie "with FedEx-like reliability" launched from thousands of miles away.[4] Doctrine calls this the ability to "mass effects" without having to "mass forces."[5] As Colonel Phillip Meilinger noted in his pamphlet *10 Propositions Regarding Airpower,*

> Precision air weapons have redefined the meaning of mass…. The result of the trend towards 'airshaft accuracy' in air war is a denigration in the importance of mass. PGMs provide density, mass per unit volume, which is a more efficient measurement of force. In short, targets are no longer massive, and neither are the aerial weapons used to neutralize them. One could argue that all targets are precision targets—even individual tanks, artillery pieces, or infantrymen. There is no logical reason why bullets or bombs should be wasted on empty air or dirt. Ideally, every shot fired should find its mark.[6]

In addition to their raw efficiencies, precision technologies also enable aerospace forces to reduce first-order "unintended" casualties and collateral damage that might otherwise result from attacking military targets.[7] Airpower theorist and author Richard Hallion believes that precision weapons provide decision makers with a source of confidence when considering the use of force "in circumstances where so-called 'collateral damage' would be either unacceptable or call into question the viability of continued military action."[8]. As a result, Hallion continues, "decision-makers have a freedom to use military force closer to non-combatant-inhabited areas in an enemy homeland (or in enemy-occupied territory) than at any previous time in military history."[9] Thomas Keaney, a co-author of the Gulf War Airpower Survey and current head of the Johns Hopkins Foreign Policy Institute believes "with all the political restraints on the air campaign…precision systems are what made the victory in Kosovo possible."[10] Of course the flip-side of this freedom is what John Foster and Larry Welch describe as an emerging political *imperative* to use precision weapons whenever possible in order to reduce casualties and collateral damage.[11]

Precision and "Discriminate Effects"

The 1995 publication of *Joint Vision 2010* gave precision technologies a more formal role in military planning when it defined precision engagement as one of four enabling operational concepts for future joint warfare. *JV2010* described it as "a system of systems that enables our forces to locate the objective or target, provide responsive command and control, generate the desired effect, assess our level of success, and retain the flexibility to reengage with precision when required."[12] Five years later, *Joint Vision* 2020 reaffirmed precision engagement and provided a more formalized definition: "Precision Engagement is the ability of joint forces to locate, surveil, discern, and track objectives or targets; select, organize, and use the correct systems; generate desired effects; assess results; and reengage with decisive speed and overwhelming operational tempo as required, throughout the full range of military operations"[13] Neither document sought to provide detailed descriptions of the systems required to achieve precision engagement, but both documents clearly characterized precision engagement as an outgrowth of technology, and both intended to frame debates over joint force requirements and capabilities. Both documents focus on the operational level of war and both characterize precision engagement to mean more than simply avoiding collateral damage but about taking specific actions to achieve well-defined outcomes.

Air Force Doctrine Document 1 (AFDD 1), *Air Force Basic Doctrine*, declares that "air and space forces today contribute directly" to achieving the joint vision concept of precision engagement.[14] AFDD 1 also identifies precision engagement as a core competency of aerospace power. However, AFDD 1 goes well past the joint vision

definitions when it claims an ability to generate "discriminate effects" directly at the strategic level of war:

> Increasingly, air and space power is providing the "scalpel" of joint service operations—the ability to forgo the brute force-on-force tactics of previous wars and apply discriminate force precisely where required. Precision engagement is the ability to command, control, and employ forces to cause discriminate strategic, operational, or tactical effects. The Air Force is clearly not the only Service capable of precise employment of its forces, but it is the Service with the greatest capacity to apply the technology and techniques of precision engagement anywhere on the face of the earth in a matter of hours or minutes.[15]

The ability to achieve *discriminate effects* at the *strategic level* through *precise application of force* seems appealing because it promises confident efficiencies and proportionality in time, lives and national treasure in the pursuit of national objectives. It suggests a degree of control that would allow us to manage a conflict, bending the adversary to our will with minimal casualties and collateral damage to either us or the adversary. It is particularly appealing in coercive situations involving more limited objectives, "one that doesn't necessarily call for the ultimate destruction of an enemy regime, but instead changes an adversary's 'mind set.'"[16] Major General (select) David Deptula, a chief architect of the Gulf War air campaign argues, "People have come to think...over tens of thousands of years of conflict that it's all about breaking things and damaging…. There are effects that we can achieve today through other means than absolute destruction…. How can the U.S. military, and, more specifically, the Air Force do that? Through the use of precision guided munitions delivered over stand-off ranges."[17]

In summary, this chapter shows how *Air Force Basic Doctrine* extends precision well beyond quantitative and physics measures of efficiency and well beyond the desire (or even imperative) to limit collateral damage. Doctrine clearly connects precision

action to discriminate strategic effects. The next chapter will take a closer look at the three key assumptions needed to actually achieve strategic precision engagement.

Notes

[1] Boyd, n.p.

[2] Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine,* 1 September 1997, 37.

[3] John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today,* December 2000, 31.

[4] "During NATO's Operation Allied Force, USAF global-strike aircraft operating out of Missouri and the United Kingdom, and US carrier aircraft and cruise missile platforms operating from the Adriatic Sea, delivered roughly two-thirds if the total allied firepower—while representing less than 20 percent of the US strike assets committed to the campaign. Through the first eight weeks of the 11-week Kosovo war, six B-2A stealth bombers flying from Whiteman AFB, Missouri alone were responsible for striking over a third of all the targets in Serbia. On the foulest-weather nights, the B-2As, each armed with 32,000 pounds of GPS-guided precision bombs deliverable in any weather, were the sole NATO strike aircraft option. Indeed, when any perceptible lull in the attack tempo would have emboldened the Serbs and caused the world to question NATO's resolve, the alliance relied on precision firepower delivered with FedEx-like reliability straight from America's heartland." General Richard E. Hawley et al., "Global Reconnaissance-Strike," *Armed Forces Journal International*, June 2000, 52.

[5] AFDD 1, 16.

[6] Colonel Phillip Meilinger, *10 Propositions Regarding Air Power* (Air Force History and Museums Program, 1995), 41, 45. Another airpower expert notes, "Those systems allowed America to inflict massive damage on Serbia with a very small number of planes, creating, as Benjamin Lambeth puts it, 'the effect of massing without having to mass.' And of the 23,000 bombs America dropped, half came from a mere 21 planes." Lawrence F. Kaplan, "Air Time." *The New Republic*, 22 January 2001, n.p.; on-line, Internet, 22 January 2001, available from http://www.tnr.com/012201/kaplan012201.html.

[7] Jeffrey A. Jackson, "Global Attack and Precision Strike," in *Air and Space Power in the New Millennium,* eds. Daniel Gouré and Christopher M. Szara (Washington, D.C.: Center for Strategic and International Studies, 1997), 108.

[8] Richard P. Hallion, "Precision Guided Munitions and the New Era of Warfare," *Air Power History,* Fall 1996, 8.

[9] Ibid, 8.

[10] Kaplan, n.p.

[11] Foster and Welch, 31.

[12] US Joint Chiefs Staff, *Joint Vision 2010: America's Military: Preparing for Tomorrow* (Washington, D.C.: US Government Printing Office, 1995), 21.

[13] US Joint Chiefs Staff, *Joint Vision 2020* (Washington, D.C.: US Government Printing Office, June 2000), 22.

[14] AFDD 1, 37.

Notes

[15] AFDD 1, 30.

[16] Christian Lowe, "Air Force QDR: America's New 911 Force?" *Defense Week* 22, no. 2 (8 January 2001): 6.

[17] Lowe, 6.

CHAPTER 3

Strategic Precision Engagement: A Closer Look at the Underlying Assumptions

> *Modern governments, in guiding their country through a war, can draw on vast masses of data and avail themselves of day-to-day, or even hour-by-hour, reports from their far-flung intelligence systems. Nonetheless, some of their key decisions have to be taken in the face of great uncertainties. But government leaders frequently fail to acknowledge these uncertainties or to take them into account in their decisions. Instead, they often implicitly assume answers to questions that they have never examined.*[1]
>
> —Fred Charles Iklé

Strategic precision engagement rests on three necessary assumptions regarding uncertainties in the decision process: the ability to define desired discriminate effects at the strategic level of war, the ability to trace the desired discriminate effects back to a triggering action, and the ability to ensure the *actual* effects generated by that action are only the discriminate ones being sought. This chapter will motivate and describe each assumption in turn. First, though, it is necessary to examine a subtle yet important distinction between technical precision and underlying accuracy.

Exactness Is Not Equivalent to Correctness

John Foster and Larry Welch assert that "precision has to do with a broader range of capabilities than just the spacial accuracy of delivery."[2] Unfortunately, there is no formal

definition of precision in the DoD Dictionary or Air Force doctrine. Mirriam-Webster's *Collegiate Dictionary* defines precision as

> 1. the quality or state of being precise : EXACTNESS
> 2a. the degree of refinement with which an operation is performed or a measurement stated – compare ACCURACY[3]

In contrast, it defines accuracy as

> 1. freedom from mistake or error : CORRECTNESS
> 2a. conformity to truth or to a standard or model : EXACTNESS
> 2b. Degree of conformity of a measure to a standard or a true value – compare PRECISION[4]

In other words, *precision* is to *accuracy* as *degree of refinement* is to *underlying truth*. More plainly, a calculation performed to many decimal places might well be described as *precise* but can only be *accurate* if the equations being used conform to the underlying truth of what is being modeled. This distinction, though subtle, is absolutely essential for a mature understanding of what is required to achieve strategic precision engagement.

Clearly, precision engagement is founded on the degree of refinement that technology provides. Notwithstanding nontrivial examples of human and technological errors that result in missed targets, technology has had profound impacts on the degree of refinement possible in munitions delivery. AFDD 1 states that "increasingly, air and space power is providing the 'scalpel'…[to] apply discriminate force precisely where required."[5] Moreover, computing power has allowed unprecedented ability to process staggering amounts of data through detailed models of physical systems and infrastructure that enable aerospace targeteers to establish very precise aim points.

But USAF doctrine clearly means more than degree of refinement when it states that "precision engagement is the ability to command, control, and employ forces to cause discriminate…effects…. It is the effect, rather than forces applied, that is the defining

factor."[6] Underlying this statement is an assumption that hitting the precisely established aim point (i.e., exactness) will in fact generate the desired discriminate effect (i.e, correctness). Elsewhere AFDD 1 describes "the precise, coordinated application of the various elements of air, space, and surface forces [exactness] which brings disproportionate pressure on enemy leaders to comply with our national will [correctness]." Under the tenets of flexibility and versatility, AFDD 1 prescribes "the swift, massive, and precise application of air, space, and information power" for parallel strategic operations.[7] Clearly refinement in weapons delivery and computing power is not sufficient to claim discriminate outcomes. The degree of selectivity and control implied by these statements demands knowledge of the underlying truths or correctness that connect the precise application of force to discriminate strategic effects.

The point is that when AFDD 1 talks about precision, it intermingles exactness and correctness. It muddies the difference between capabilities that can be verified through direct technical experimentation and capabilities that can only be *postulated* from airpower theories not amenable to direct proof and from extrapolation of a known past to an unknown future. In the case of strategic precision engagement, the three assumptions identified at the start of this chapter are the structural elements revealed by clearly separating exactness from correctness in AFDD 1's use of the term precision.

A Conceptual Model

Figure 1 illustrates a conceptual model for analyzing strategic precision engagement. This model provides a basic structure for discussing the assumptions of strategic precision engagement, but it is intentionally generic in order to avoid the maxims and metaphors that Peter Faber cites as "pathologies" of airpower theory.[8]

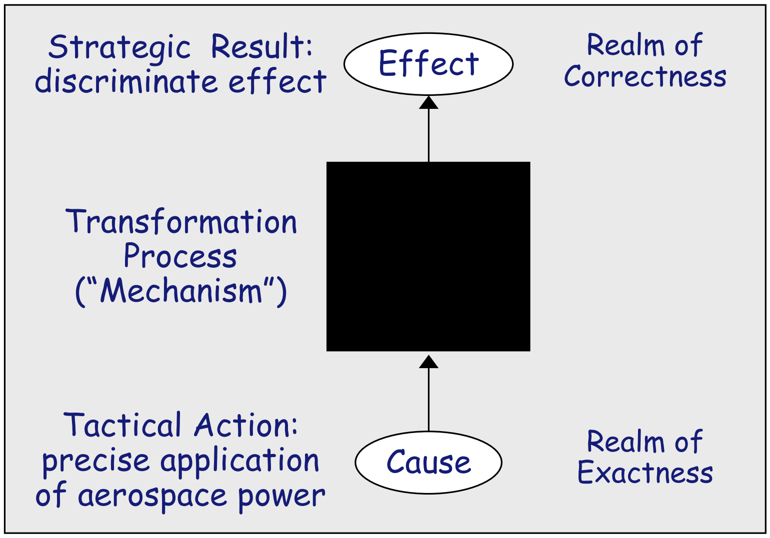

Figure 1. Black Box Linking Cause to Effect

Defining the Desired Discriminate Effects

It does not make sense to talk about discriminate effects unless those effects are clearly defined in advance. If for no other reason, the decision maker must communicate the discriminate outcome to planners who must develop the means to achieve it. Foster and Welch argue the need for "precision of purpose and objectives" to ensure the most appropriate application of high-technology weapons.[9]

Just as important, the term discriminate effects implies something far less than the cataclysmic collapse of the adversary. Indeed, strategic precision engagement derives much of its appeal by promising limited political objectives through coercive but not catastrophic measures. While in some cases the political leadership may seek the cascading collapse of the adversary, it does not seem reasonable to characterize such an outcome as discriminate. Achieving precision engagement at the strategic level of war requires an explicit description of effects that support political outcomes expressed as limited objectives.

Aerospace commanders have always sought to define and achieve effects. But more recent concepts such as "effects based targeting" and "effects based operations" have helped mature the discussion of how best to define effects relative to aerospace means.[10] The CINCs in particular welcome these efforts. In a recent conference on aerospace power, General Anthony Zinni, former commander-in-chief, US Central Command, espoused the belief that effects-based approaches are valuable because they "force[s] senior commanders and political leaders to define what they want to accomplish." He illustrated his point with the example of OPERATION DESERT FOX and said effects-based thinking helped decision makers develop a realistic definition of what *could* be achieved—in this case a narrower effect of delaying rather than destroying Iraqi missile programs. Gen Zinni credited this approach with enabling planners to design a successful operation that achieved the desired political objectives.[11]

Interestingly, while *Air Force Basic Doctrine* refers to tactical, operational and strategic effects, synergistic effects, parallel effects, decisive effects, and overwhelming effects, it fails to actually define the term effects.[12] The closest to an actual definition appears in a discussion of attacking enemy centers of gravity (COGs) where the doctrine states, "Strategic attack objectives often include producing effects to demoralize the enemy's leadership, military forces, and population, thus affecting an adversary's capability to continue the conflict."[13]

AFDD 2-1, *Air Warfare*, published in January 2000, more than two years after AFDD 1, actually does provide some definitions. It states that effects are "the operational- or strategic-level outcomes that [the broad, fundamental, and continuing activities of aerospace power] are intended to produce."[14] It further states that a

"strategic effect is the disruption of the enemy's strategy, ability, or will to wage war or carry out aggressive activity through destruction or disruption of their COGs or other vital target sets, including command elements, war production assets, fielded forces, and key supporting infrastructure."[15] AFDD 2-1 also makes a distinction between direct and indirect effects:

> Direct effects are those that result immediately from attacking the target set or sets involved. For example, bombing enemy surface-to-air missile (SAM) sites and the associated command and control (C2) facilities may directly result in SAM and radar sites destroyed, but the cumulative indirect effect may be to achieve aerospace superiority across the theater, which in turn allows other effects to be imposed on the enemy. Detailed analysis of interconnected indirect effects can easily become complex, and such effects are nearly impossible to predict exactly.[16]

The draft of AFDD 2-1.2, *Strategic Attack*, describes effects as "distinctive and desired results" and says they "may occur at all levels of war."[17] It specifically relates effects to "physical or psychological outcomes…[that] change the adversary's behavior or exceed its willingness to resist" and counsels that "careful analysis" is required to ensure effects contribute to the overall objectives of the National Command Authority and Joint Force Commander.[18]

Further insights into the nature of effects and the challenges of defining discriminate effects are emerging from a recent study on effects-based operations, sponsored by the Operational Plans and Interoperability Directorate (J-7) of the Joint Staff and conducted by the Joint Advanced Warfighting Project (JAWP) at the Institute for Defense Analyses (IDA). This study describes four classes of effects: desired effects on the enemy's capabilities, desired effects on enemy assessments and actions, undesired effects, and unexpected effects.[19] The first three categories offer important insights into what's

required to describe discriminate effects; this paper will address the fourth category during the discussion on boundedness.

The JAWP study notes that certain effects depend entirely on blue action whereas others depend on how the enemy *reacts* to blue's actions.[20] Physical destruction of surface-to-air missile sites means the enemy no longer has the option of launching missiles from those particular sites—an effect on the enemy's actual capability that resulted solely from blue action. At some point, the enemy may decide to stop using his remaining launchers for fear that they, too, will be destroyed. In that case, Blue's action has had an effect on the enemy's assessment of the situation and his actions. The former effect is relatively permanent and amenable to direct measurement—e.g., traditional battle damage assessment. One must use indirect means to infer the latter type of effect; logically, such effects persist as long as the enemy's assessment remains unchanged. The JAWP study notes that these two types of desired effects may change enemy options and actual behaviors but pointedly cautions against assuming either type necessarily changes the enemy's underlying *will*.

The second contribution of the JAWP study is the need to explicitly account for undesireable effects, which the study argues "are usually easier to understand after the fact than to predict."[21] Neither AFDD 1 nor AFDD 2-1 explicitly address the possibility of undesireable effects but the draft version of AFDD 2-1.2 promises to fill this gap with its discussion of collateral effects:

> Commanders should be aware of possible collateral effects from strategic attack operations. These are unintentional or incidental direct or indirect effects causing injury or damage to persons or objects. Besides studying possible first-order collateral effects, evaluation of potential collateral effects should include consideration of second- and third-order systemic effects. For example, destroying utility systems providing power to the

> enemy's military C2 network may also have a debilitating effect on health and public services supporting the civilian population. These negative indirect effects can work against achieving friendly force objectives and activate a friendly COG (e.g., public opinion) against a military operation. Collateral effects may or may not contribute to achieving NCA or JFC objectives and they can be a major factor in determining whether or not to employ strategic attack against a particular target.[22]

Historian Richard Hallion provides an excellent example of an undesirable effect. He notes that "well-publicized attacks against bridges in downtown Baghdad, coupled with a precision attack against the Al Firdos command and control bunker that killed several hundred individuals using it as a shelter, generated a political reaction that included shutting down the strategic air campaign against Baghdad for ten days. This occurred despite clear evidence that the Hussein regime was trying to reconstitute key leadership functions destroyed or degraded by previous attack."[23] Based on this example, it does not seem reasonable to describe an effect as discriminate if its dominant components are undesired.

In sum, a necessary assumption to precision engagement at the strategic level of war is the ability to define effects discriminately. Whereas some effects are direct and can be described in terms of raw capabilities; others are indirect and must be described in terms of enemy choices. Moreover, the possibility of undesirable effects requires an explicit differentiation between what the decision maker wants, what he doesn't want but can accept, and what he cannot accept at all. This is not likely to be simple even in cases of large scale threats to US vital interests. General John Jumper compares the simplicity of Eisenhower's mission in the European Theater of Operations to that of the coalition forces in DESERT STORM where "we had 26 pages of [rules of engagement], limits, concerns and caveats."[24] How much more challenging it will be to define the full spectrum of desired and undesired effects in cases involving far more limited objectives

and taking place in a complex strategic environment? Achieving precision engagement at the strategic level of war assumes that this is possible.

Tracing Effects Back to Causes

In a recent article in *Aerospace Power Journal*, Col Phillip Meilinger notes that the history of airpower has in some sense been a search to understand the connection between aerospace action and strategic effect. He notes that from the airpower's earliest days, various theories and models have attempted to define, implicitly or explicitly and to varying degrees, those "mechanisms" or linkages.[25] Yet Faber argues that "given the overconcentration by early theorists on the mechanics of targeting, it should be no surprise that the causal relationship between aerial attacks and political outcomes remains murky. In fact, a clear exposition of this relationship remains the Holy Grail of airpower theory."[26] Unfortunately strategic precision engagement depends on that clear exposition.

Foster and Welch argue that "in recent years, physics and other sciences have contributed extensively to an emerging national-security goal that 'for every desired battlefield outcome there should be a precise and well-defined action.'"[27] *Air Force Basic Doctrine* extends this causal relationship beyond battlefield outcomes and specifically refers to strategic outcomes. It states that "aerospace forces can often strike directly at key target sets that have strategic results, without having to go through the process of drawn-out attrition at the tactical level of war. Analyzing the enemy for such critical targets is a fundamental part of aerospace warfare."[28] In the words of airpower expert Edward Luttwak, "all the strategy [for airpower] lies in the selection and prioritization of targets."[29] Strategic precision engagement assumes the airpower planner

is able to trace the discriminate strategic effect back to some specific tactical action—i.e., a target—that generates it. This black box in Figure 1 is essentially a representation of that relationship.

Air Warfare emphasizes the need to articulate the connections between cause and effect, noting that Joint Air Operations Plans "should include a desired outcome, target set, and a mechanism for achieving the desired outcome" and that there should be a "demonstrated link between [a] target's destruction and the achievement of aerospace and overall military objectives."[30] AFDD 2-1 cautions that "failure to properly analyze the mechanism that ties tactical results to strategic effects has historically been the shortcoming of both airpower theorists and strategists."[31] The important point here is similar to one that Major John Carter makes in *Airpower and the Cult of the Offensive*, where he warns not to confuse the executability of an aerospace operations plan with the effectiveness of that plan.[32]

Former Air Force Chief of Staff General Ronald Fogelman illustrated the challenges of determining mechanisms when he wrote, "It is easy to quantify the effects of air power at the tactical level; for example, how many trucks and how many tanks are destroyed. These are results we can measure and compare with results from other weapons. It is difficult to show the cause-and-effect of air power when it is used strategically and innovatively."[33] Other airpower authorities have argued that "the Air Force's increasing ability routinely to hit targets with great accuracy has not been matched by a commensurate understanding of exactly which targets to hit to achieve specific outcomes—what is now called 'effects-based targeting.'"[34] Obviously this situation must change if aerospace power is to achieve discriminate strategic effects that are limited and

intended to coerce rather than completely annihilate an enemy.[35] This is why strategic precision engagement assumes that the black box in Figure 1 exists and that there is some algorithm that enables aerospace planners to trace desired discriminate effects back to their triggering actions.

Uncertainties in Ensuring Desired Effects

Even the most enthusiastic proponents of high-technology approaches to warfare do not predict that future commanders will have *perfect* battlespace knowledge (though at least one military futurist speculates that technology might enable "near perfect" information).[36] Since strategic precision engagement cannot assume perfect information, it will depend on some approximation of the relationship depicted in Figure 1. The question is whether the uncertainties introduced by such an approximation are acceptable relative to the desired discriminate effect.

Consider the example of Operation Allied Force. General Wesley Clark, former Supreme Allied Commander, Europe and Commander-in-chief, U.S. European Command during Operational Allied Force, argues that NATO's political leadership was very sensitive to casualties and collateral damage. He felt that uncertainties came to dominate even "routine" battlefield targeting decisions: "We needed to know what was inside of the trucks. When we couldn't find out, we stopped bombing trucks. We needed to know what was inside of the buildings. When we couldn't find out, we stopped bombing buildings. We needed to know what was under the camouflage net. When we couldn't find out, we stopped bombing the camouflage nets."[37] The "exactness" of the weapons was not the main issue. The main issue was whether striking a particular set of geographic coordinates would in fact produce an effect that was *acceptable*, even if it

wasn't precisely the effect that was *intended*. Nobody wanted an Allied Force equivalent to the Al Firdos bunker; the political fallout might have had serious negative consequences for the alliance as a whole.

Strategic precision engagement can accept the uncertainties of imperfect information as long as it is possible to ensure that, given a good approximation of the black box, the differences between *actual* effects and the intended discriminate effects will be predictably small in terms of time, resources, lives and overall political capital. This is why strategic precision engagement assumes an ability to ensure the actual effects generated by that action are only the discriminate ones being sought.

An Operationalized View of Uncertainties

The previous section describes a key assumption regarding the nature of uncertainties in strategic precision engagement. It notes that the concept does not require absolute elimination of uncertainties. This section looks at those remaining uncertainties from the perspective of the decision makers and planners who must interact to implement strategic precision engagement.

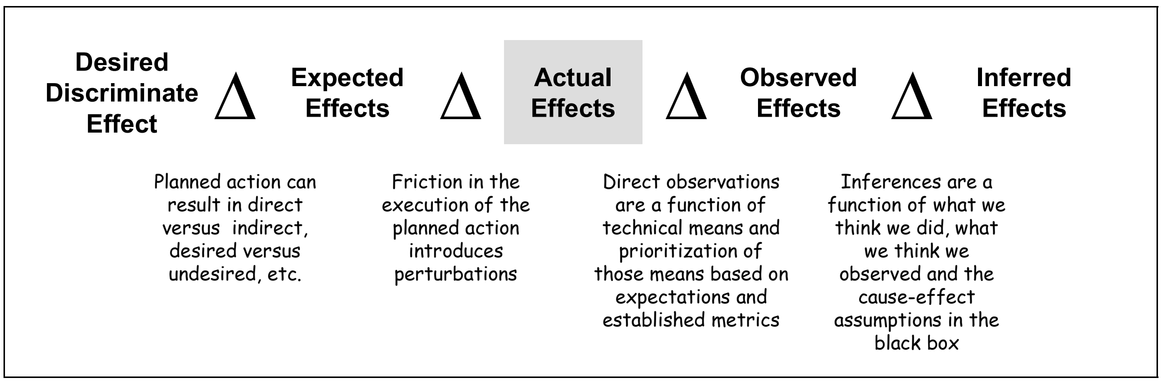

Figure 2. Uncertainties in Strategic Precision Engagement

Figure 2 shows that there are uncertainties in the process of narrowing the difference between what decision makers desire and what planners expect to occur. When the decision maker specifies the discriminate effect (first assumption), the planners use their current approximation of the black box algorithm to trace back to a candidate tactical action (second assumption). Reversing the algorithm may reveal that the candidate action will generate additional effects not considered by the decision maker in his original specification. Clearly the way to reduce uncertainty here is to give the decision maker an opportunity to refine his or her definition of the desired effect and repeat the process until the decision maker is satisfied that he has made an informed choice. This does not guarantee complete closure but the third assumption provides confidence that the remaining uncertainties are acceptably small.

Unless we can assume away weapons malfunctions, operator error, etc., uncertainties will enter into the technical execution of the planned action. The third assumption is valuable here because it provides confidence that small errors or perturbations will lead to relatively small deviations between what was expected and what actually occurs.

There is another source of uncertainty to consider as result of not assuming perfect knowledge: the difference between direct observation of action and effect versus actual action and effect. A comprehensive capture and analysis of all directly observable data is virtually impossible; so planners must develop data collection priorities based on the black box approximation, the planned action and the expected effects. Any data not captured or analyzed is a potential source of uncertainty regarding the action as it *actually* occurred, the full range of subsequent effects as they *actually* occur.

Finally, one of the most important sources of uncertainty derives from the process of developing inferences from direct observations. Direct observation can confirm that a weapon hit its aim point or that a bridge is physically destroyed. However, some important strategic effects are not amenable to direct measurement. Aerospace authority and author Barry Watts points out that "one can measure temperature or mass readily enough with a single number, but social utility or the second-order consequences of wartime decisions years afterwards may be another matter entirely given the spatial-temporal distribution of the relevant information and the limits of human cognition."[38]

Inferences are a function of what we *think* we did, what we *think* we observed and what we *think* to be true regarding the cause-effect relationships of the black box. When the inferred result matches the expected result, planners and decision makers are likely to accept their approximation of the black box algorithm as valid, potentially reinforcing

latent biases. If there are discrepancies between the expected effect and the inferred effects, planners might ignore the data that caused the contradiction as an anomaly or data hiccup, augment the algorithm with a new parameter that explains the discrepancy (what positivists might call a "hidden variable"), or scrap the old algorithm and pick a new one all together. Such judgments are crucial since inferences feed into subsequent decisions. If Iklé is correct when he warns of the tendency of warring governments to "implicitly assume answers to questions… never examined," then decision makers and planners must take extra care to guard against this potentially dangerous source of uncertainty.

Summary

This chapter showed how *Air Force Basic Doctrine* blurs the distinction between exactness and correctness when it refers to precision. In effect, doctrine suggests technical improvements in the exactness of weapons result in ipso facto improvements in the correctness of those actions relative to achieving desired discriminate effects. Clearly, strategic precision engagement depends on both exactness and correctness but the main focus of this paper is the issue of correctness as expressed by three necessary assumptions: correctness in defining the desired discriminate effects at the strategic level of war, correctness in tracing the desired discriminate effects back to a triggering action, and correctness in determining the actual effects generated by that action are only the discriminate ones being sought.

In deconstructing strategic precision engagement into its underlying assumptions, this chapter has illustrated some potential difficulties with those assumptions. But this is only a first cut, and further evidence is needed. While history might provide a source of

additional evidence, this paper takes a different approach and applies insights from the study of nonlinear and complex systems. As the next chapter will show, those insights cast further doubt over the reasonableness of the assumptions behind strategic precision engagement.

Notes

[1] Fred Charles Iklé, *Every War Must End* (revised edition) (New York: Columbia University Press, 1991), 17.

[2] John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today,* December 2000, 31.

[3] "precision," *Merriam-Webster OnLine: Collegiate Dictionary, 2000,* n.p.; on-line, Internet, 10 October 2000, available from http://www.merriam-webster.com/dictionary.htm.

[4] "accuracy," *Merriam-Webster OnLine: Collegiate Dictionary, 2000,* n.p.; on-line, Internet, 10 October 2000, available from http://www.merriam-webster.com/dictionary.htm.

[5] Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine,* 1 September 1997, 30.

[6] AFDD 1, 30.

[7] Ibid, 24.

[8] Faber, n.p.

[9] Foster and Welch, 31.

[10] For an Air Force Doctrine Center perspective on these efforts, see Chief of Staff of the Air Force, "Doctrine Watch #13: Effects-Based Operations (EBO)," 30 November 2000, n.p.; on-line, Internet, available from http://www.doctrine.af.mil/DoctrineWatch/DoctrineWatch.asp?Article=13.

[11] Gen Anthony Zinni, former commander-in-chief, US Central Command, "America's Aerospace Force – Integration Across the Joint Spectrum," address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 8 February 2001.

[12] Nor was a definition included with the publication of AFDD 1-2, Air Force Glossary, in July 1999, two years after the publication of AFDD 1.

[13] AFDD 1, 51.

[14] Air Force Doctrine Document (AFDD) 2-1, *Air Warfare*, 22 January 2000, 6-7.

[15] Ibid, 7.

[16] Ibid.

[17] The document continues with "Effects-based planning and execution should demonstrate clear relationships between the NCA or JFC objectives, the effects that achieve those objectives and the aerospace power operations that produce the desired effects." Air Force Doctrine Document (AFDD) 2-1.2, *Strategic Attack,* 1 January 2000 (draft), 9.

[18] AFDD 2-1.2, 17.

Notes

[19] "New Perspectives on Effects-Based Operations," draft annotated briefing, Institute for Defense Analyses (IDA) Joint Advanced Warfighting Project (JAWP), 6 March 2001, 17-18.

[20] Ibid, 17.

[21] Ibid.

[22] AFDD 2-1.2, 18-19.

[23] Richard P. Hallion, "Precision Guided Munitions and the New Era of Warfare," *Air Power History,* Fall 1996, 8-9.

[24] Gen John P. Jumper, commander, Air Combat Command, keynote address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 8 February 2001.

[25] Col Phillip S. Meilinger, "Air Strategy: Targeting for Effect," *Aerospace Power Journal* XIII, no. 4 (Winter 1999): 48-61; on-line, Internet, 8 January 2001, available from http://www.airpower.maxwell.af.mil/airchronicles/apj/apj99/win99/meiling.pdf.

[26] Lt Col Peter Faber, "Competing Theories of Airpower: A Language for Analysis," paper presented at the Air and Space Power Doctrine Symposium, Maxwell AFB, Ala., 30 April 1996, n.p.; on-line, Internet, 9 February 2001, available from http://www.airpower.maxwell.af.mil/airchronicles/presentation/faber.html.

[27] Foster and Welch, 31.

[28] AFDD 2-1, 7.

[29] Edward N. Luttwak, "Air Power in US Military Strategy," in *The Future of Airpower in the Aftermath of the Gulf War*, ed. Richard H. Schultz Jr. (Maxwell AFB, Ala.: Air University Press, July 1992), 24.

[30] AFDD 2-1, 2, 51.

[31] Ibid, 3. Interestingly, while doctrine uses the term mechanism to refer to the connection between action and effect, it does not provide a formal definition of the term mechanism. AFDD 2-1's glossary incorporates the term mechanism into the definitions of direct and indirect effects. It defines direct effect as the "result of actions with no intervening effect or mechanism between act and outcome. Direct effects are usually immediate and easily recognizable." An indirect effect is the "result created through an intermediate effect or mechanism to produce the final outcome, which may be physical or psychological in nature. Indirect effects tend to be delayed and may be difficult to recognize." AFDD 2-1, 106, 107. Even the most recent drafts of AFDD 2-1.2, *Strategic Attack*, fails to provide a definition even though it uses the term repeatedly.

[32] Major John R. Carter, *Airpower and the Cult of the Offensive*, College of Aerospace Doctrine, Research and Education Paper (Maxwell AFB, Ala.: Air University Press, October 1998), 92.

[33] Gen Ronald R. Fogelman, "Introduction" in *Air and Space Power in the New Millennium,* eds. Daniel Gouré and Christopher M. Szara (Washington, D.C.: Center for Strategic and International Studies, 1997), xxix.

[34] James A. Kitfield, "Another Look at the Air War that Was," *Air Force Magazine* 82, no. 10 (October 1999): n.p.; online, Internet, available from http://www.afa.org/magazine/1099eaker.html.

[35] Kitfield, n.p.

Notes

[36] David S. Alberts, "The Future of Command and Control with DBK," in *Dominant Battlespace Knowledge* (revised edition), eds. Martin C. Libicki and Stuart E. Johnson (Washington, D.C.: National Defense University Press, 1996), n.p.; on-line, Internet, 5 October 2000, available from http://www.ndu.edu/inss/books/dbk/dbkch05.html.

[37] Gen Wesley Clark, former supreme allied commander Europe and commander-in-chief, United States European Command, "21st Century Coalition Warfare – Opportunities and Concerns for Aerospace Power," keynote address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 7 February 2001.

[38] Barry D. Watts, *Clausewitzian Friction and Future War,* Institute for National Strategic Studies McNair Paper 52 (Washington, D.C.: National Defense University Press, October 1996), 129.

CHAPTER 4

Are The Assumptions Reasonable? Insights from the Study of Complex Adaptive Systems

"In war the chief incalculable is the human will."

—B. H. Liddell Hart

The study of nonlinear and complex interactive systems offers a number of insights into the reasonableness of the assumptions presented in the previous chapter. This chapter reviews key characteristics of such systems and discusses the implications for achieving precision engagement at the strategic level of war.

Nonlinearity and Complex Adaptive Systems

One can describe physical systems as either linear or nonlinear. Linear systems exhibit proportionality between input and output. Small changes in the value of an input will result in a proportionately small deviations of the output. Linear systems also exhibit the property that the whole is equal to the sum of it parts. Any system that does not exhibit both properties is said to be nonlinear.[1] In nonlinear systems, it is possible for small perturbations in system inputs to cause dramatic changes in system outputs and the system as a whole can be quite different than the sum of its component parts.

In his book, *Chaos: Making a New* Science, James Gleick points out that seemingly simple systems can produce highly nonlinear behaviors. As one example among many,

he describes a well-known model population growth known as the logistic equation. This equation consists of one variable representing the population size, and one control parameter used to represent how the population responds to its environmental conditions. Over certain ranges of values, the tiniest of changes in the control parameter will dramatically affect the behavior of the system.[2] The logistics equations illustrate that nonlinear systems can be highly sensitive to tiny errors in estimating control parameters, including those introduced when real world analog values are converted into finite digital representations for the sake of high-speed computation. Gleick notes that such systems may be completely deterministic (i.e., not random) and yet defy computability and long-term prediction.

Detailed prediction becomes far more complicated when the number of system components multiply. James Maxfield defines a complex adaptive system as an "open ended system of many heterogeneous agents who interact non-linearly over time with each other and their environment and who are capable of adapting their behavior based on experience."[3] He describes how the overall output of such systems cannot be predicted through decomposition into the system's component parts and decision rules because these system can exhibit self-organization, evolutionary trajectories, co-evolution and punctuated equilibrium.[4] Robert Jervis explains that in such systems "strategies depend on the strategies of others." Each individual action changes the environment in which subsequent system interactions take place. The collective "behavior" of such systems can be very complex and can defy detailed prediction.

The Black Box Involves Nonlinearity and Complex Interactions

That nonlinearities are inherent in warfare is not a new idea. Author Alan Beyerchen notes that Clausewitz acknowledged nonlinearity, even though he did not term it such. For instance, Clausewitz writes in *On War* "the same political object can elicit differing reactions from different peoples, and even from the same people at different times.... Between two peoples and two states there can be such tensions, such a mass of inflammable material, that the slightest quarrel can produce a wholly disproportionate effect—a real explosion."[5] More recently, Watts used non-linearity to reconstruct the Clausewitzian concept of general friction to include "the structural nonlinearity of combat processes which can give rise to the long-term unpredictability of results and outcomes by magnifying the effects of unknowable small differences and unforeseen events (or, conversely, producing negligible results from large inputs)."[6]

AFDD 1 not only acknowledges the existence of nonlinearity, it characterizes it as something to be exploited: "The proper application of a coordinated force can produce effects that exceed the individual contributions of the individual forces employed separately."[7] The synergy described by AFDD 1 can only be possible if the black box cause-effect relationship is nonlinear. Moreover, the effect must be the product of multiple interactions within the black box. In assessing the impact of airpower during the Gulf War, one military planner commented that "If there is a lesson to be gained from the Desert Storm campaign, it is that airmen should carefully examine their linkages between all target sets and the intended effect on the enemy."[8] Linkages represent the presence of interactions that are a defining characteristic of complex systems.

Assuming that war is nonlinear and made up of complex interactions, then the descriptive characteristics of nonlinear and complex systems should lead to skepticism over the reasonableness of the assumptions described in the previous chapter. First, underlying nonlinearities increase uncertainties about the full spectrum of effects that may occur subsequent to an action. According to Jervis, "In a system, the chains of consequences extend over time and many areas: the effects of action are always multiple."[9] "In politics, connections are often more idiosyncratic, but their existence guarantees that here too most actions, no matter how well targeted, will have multiple effects."[10] Alvin and Heidi Toffler point out, "The greater the interdependence, the more countries are involved and the more complex and ramified the consequences. Yet interrelationships are already so tangled and complex that it is nearly impossible for even the brightest politicians and experts to grasp the first- or second-order consequences of their own decisions."[11] Planners and decision makers will be hard-pressed to define effects with a high degree of specificity—what is desired and what is not desired—in a realm where we may not even foresee the possibility of a particular evolutionary direction.

Second, Jervis cautions against assuming we can predict behavior of the whole through a detailed examination of the component parts. That doesn't mean detailed analyses of individual components are pointless—detailed analyses offer insights that might not otherwise be known. In fact, organizations such as the Joint Warfare Analysis Center exist for that very purpose and can perform highly detailed and accurate models of adversary infrastructure to assist joint force commanders with campaign planning.[12] However, one cannot conclude that a detailed deconstruction will allow prediction of

discriminate aggregate behavior and it is this aggregate behavior which is important at the strategic level of war. This makes discovery of a tight cause-effect linkage from tactical action to strategic effect highly problematic.

Third, when generating effects at the strategic level of war, perturbations matter. Unfortunately, there are many sources of perturbations that are outside the direct control of military decision makers. In his classic study of the national security decision making, Graham Allison found that vital decisions may not involve rational, value-optimizing, synchronized choices across all instruments of power. One reason for this is that large organizations tend to deal with the unfamiliar by appealing to in-place standard operating procedures. These procedures contain built-in assumptions that, unfortunately, are not always readily apparent to those executing the procedures.[13] The assumptions may or may not apply to the particular circumstances—i.e., black box—at hand but they are hidden and not subjected to scrutiny. Yet if any assumption is invalid, the prescribed actions will be based on a black box that is different from the actual black box at hand. In effect, this difference introduces a perturbation relative to the action that *would have* been taken had the organization used more "correct" assumptions. Allison also found that the bureaucratic political competition of key policy makers can introduce other perturbations—sometimes as a result of misunderstandings and foul-ups.[14] On top of all that, external actors can generate inputs or perturbations to the black box that the military cannot control and may not even be aware of. Unfortunately, complexity implies that one cannot reliably predict which perturbations will cause divergence from the intended strategic effect.

Finally, the interactions internal to the black box can change over time, and can change unexpectedly. Jervis notes that “politics, like nature, rarely settles down as each dispute, policy, or action affects others and re-shapes the political landscape, inhibiting some behaviors and enabling others.”[15] Individual interactions are not independent but take place within the context of all the other interactions—each action provides the initial conditions for all subsequent actions. Moreover, Watts notes that the significance of some interactions cannot be known until “individuals are confronted with particular…choices in particular circumstances. Other elements, especially those having to do with long-term consequences, can only be known later in time because of the subsequent contingent choices open to other individuals.”[16] A linkage once dismissed as insignificant could later become critical. Watts describes this as the “inaccessibility of critical information.”[17] The net effect is that “initial behaviors and outcomes often influence later ones, producing powerful dynamics that explain change over time and that cannot be captured by labeling one set of elements ‘causes’ and other ‘effects.’”[18] Van Crevald captured this when he wrote, “The underlying logic of war is, therefore, not linear but paradoxical. The same action will not always lead to the same result.”[19]

The problem is that strategic precision engagement wants to have it both ways—view of war that acknowledges and even seeks to exploit nonlinearities against an adversary while simultaneously suggesting that such nonlinearities can be predicted and controlled in ways that produce discriminate outcomes to our benefit. If the black box is characterized by nonlinearity and complex interactions then, as a minimum, we should be doubtful over our ability to guarantee desired discriminate effects. If nothing else, the passage of time represents opportunities for additional perturbations and evolution to

occur. The absence of caution could easily lead a mindset that seeks a fait accompli, something USMC doctrine effectively warns against:

> The fait accompli is another potential strategic pitfall. It is immensely attractive to political leaders because it seems neat and clean—even "surgical." The danger is that many attempted faits accomplis end up as merely the opening gambit in what turns out to be a long-term conflict or commitment. This result was normally not intended or desired by those who initiated the confrontation. In 1983, the Argentines assumed that their swift seizure of the nearby Falkland Islands could not be reversed by far-off, postimperial Britain and that therefore Britain would make no effort to do so. They were wrong on both counts.[20]

General John Jumper's put it more succinctly when he said, "Don't ever start anything where the only plan consists of one phase."[21]

A Control-Feedback Loop

The previous discussion reveals weaknesses in the assumptions required by strategic precision engagement to connect precision action to discriminate effects. Still, technology has provided a means of successfully managing and controlling some highly nonlinear processes using control-feedback processes that leverage short-term predictability to achieve longer term outcomes. Alvin Saperstein, writing in *American Scientist*, suggested that such control might be possible in a strategic sense:

> The similarity between the calculated behavior of complexity-dominated systems and the behavior of sociopolitical systems in the real world gives considerable credence to the idea that the real world is dominated by deterministic rules and that the observed contingency is due to the occasional sensitivity of the real system to minor, but always present, random perturbations. This paradigm is quite different from that which supports the observed contingencies of the world on an underlying stochastic foundation. The choice between the two approaches to sociopolitical reality is not purely academic but has profound practical consequences. Both paradigms rule out the possibility of long-term prediction, but the complexity scheme does allow for short-term prediction and thus offers the possibility of control.[22]

The next chapter examines what would be required of a technological approach that predicts short term results, and reacts with such speed in decision and application of force that it is possible to nudge the system incrementally *in the direction* of the desired discriminate effect.

Notes

[1] Alan D. Beyerchen, "Clausewitz, Nonlinearity and the Unpredictability of War," International Security 17, no. 3 (Winter 1992): 59-90, in *Coping with the Bounds: Speculations on Nonlinearity in Military Affairs,* ed. Thomas J. Czerwinski (Washington, D.C.: National Defense University Press, May 1998), n.p.; on-line, Internet, 5 October 2000, available from http://www.dodccrp.org/copind.htm.

[2] James Gleick, *Chaos: Making a New Science* (New York: Penguin Books, 1988), 63-65.

[3] Robert R. Maxfield, "Complexity and Organization Management," in *Complexity, Global Politics and National Security,* eds. Thomas J. Czerwinski and David S. Alberts (Washington, D.C.: National Defense University Press, 1997), n.p.; on-line, Internet, 2 October 2000, available from http://www.ndu.edu/inss/books/complexity/ch08.html.

[4] Ibid.

[5] Carl von Clausewitz, *On War*, ed. and trans. Michael Howard and Peter Paret (Princeton: Princeton University Press, 1976), 81.

[6] Barry D. Watts, *Clausewitzian Friction and Future War,* Institute for National Strategic Studies McNair Paper 52 (Washington, D.C.: National Defense University Press, October 1996), 120.

[7] Air Force Doctrine Document (AFDD) 1, *Air Force Basic Doctrine,* 1 September 1997, 24.

[8] Col Mark Gunzinger, "Towards Flexible Theater Air Warfare Doctrine," *Air Power History*, Winter 1996, 57.

[9] Robert Jervis, "Complex Systems: The Role of Interactions," in Complexity, Global Politics and National Security, eds. Thomas J. Czerwinski and David S. Alberts (Washington, D.C.: National Defense University Press, 1997), n.p.; on-line, Internet, 2 October 2000, available from http://www.ndu.edu/inss/books/complexity/ch03.html.

[10] Jervis, n.p. Alvin and Heidi Toffler note "What many foreign policy pundits still fail to appreciate is that when systems are 'far from equilibrium' they behave in bizarre ways that violate the usual rules. They become nonlinear—which means that small inputs can trigger gigantic effects. A tiny number of negative votes in tiny Denmark was enough to delay or derail the entire process of European integration." Alvin and Heidi Toffler, *War and Anti-War* (New York: Little, Brown and Co., 1993), 250.

[11] Alvin and Heidi Toffler, *War and Anti-War* (New York: Little, Brown and Co., 1993), 211.

[12] At a 1999 Defense Colloquium on Information Operations, the Joint Staff's Deputy Director for Information Operations noted that "The Joint Warfare Analysis Center…can tell you not just how a power plant or a rail system is built, but exactly what

is involved in keeping that system up and making that system efficient. One of the terms I've learned from these guys is SCADA—Supervisory Control and Data Acquisition….SCADA basically is the computer control for a power system or railroad or sewer system or water system. We rely more and more on those kinds of systems as potential targets, and sometimes very lucrative targets, as we go after adversaries." Major General Bruce A. Wright, deputy director for information operations, Joint Chiefs of Staff, "Information Operations, Operational Level Support to the JFC," address to the Defense Colloquium on Information Operations, 24 March 1999, n.p.; on-line, Internet, available from http://www.aef.org/symposia/wright.html.

[13] Graham T. Allison, *Essence of Decision*: *Explaining the Cuban Missile Crisis* (Boston: Little, Brown and Company, 1971), 89.

[14] Allison, 175.

[15] Jervis, n.p. He further notes "Obvious examples are provided by many diplomatic and military surprises: a state believes that the obstacles to a course of action are so great that the adversary could not undertake it; the state therefore does little to block or prepare for that action; the adversary therefore works especially hard to see if he can make it succeed."

[16] Watts, 71.

[17] Ibid, 69. Jervis suggests that some changes are not evident until a "critical mass is assembled."

[18] Jervis, n.p.

[19] Martin Van Crevald, *Technology and War: From 2000 B.C. to the Present* (New York: The Free Press, 1989), 316.

[20] Marine Corps Doctrine Publication (MCDP) 1-1, *Strategy*, 12 November 1997, 99.

[21] Gen John P. Jumper, commander, Air Combat Command, keynote address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 8 February 2001.

[22] Alvin M. Saperstein, "War and Chaos," American Scientist 83, no. 6 (November/December 1995), n.p.; on-line, Internet, 25 September 2000, available from http://www.sigmaxi.org/amsci/articles/95articles/Saperstein.html.

CHAPTER 5

Can Technology Provide the Necessary Fix?

> *With advanced integrated aerospace capabilities, networked into a system of systems, we'll provide the ability to find, fix, assess, track, target and engage anything of military significance, anywhere. We'll transition from the ability to do that in hours to the ability to do it in minutes. Information superiority will be a vital enabler of that capability. We will continually improve our ability to make better decisions, faster—faster than an enemy can react—to assure decision dominance over adversaries.*[1]
>
> —AF2020

The previous chapter revealed important weaknesses in the assumptions required for strategic precision engagement to connect precision action to discriminate strategic effects. These weaknesses suggest skepticism that the algorithm to the black box can be determined and programmed. Still, there is some optimism over technology's ability to perform highly accurate observations, conduct rapid analysis, provide *short term* prediction and guide precision actions. Could technology operationalize a construct built on short-term control-feedback that approximates precision engagement at the strategic level of war?

Technology Opportunities

While *Air Force Basic Doctrine* doesn't claim technology will eliminate friction in war it does cite technology as a positive factor in reducing friction's effects.[2] There are a number of reasons for technological optimism: witness the phenomenal advances in the

means available to gather and process information over the past decade. Vice CJCS Admiral Owens provides a representative perspective. In his book, *Lifting the Fog of War* he argues the case for a revolution in military affairs built on a system of systems that combines the technologies of battlespace awareness, C4I and precision force. He believes current technology demonstrates the potential to give military commanders a real time, "omniscient view of the battlefield" allowing them to "'see' virtually everything of military significance," regardless of weather, terrain and in day or night.[3] At the same time Owens does not expect the system of systems to provide perfect knowledge or ensure perfect execution, but that it could provide a critical relative advantage over less technologically enabled opponents.[4] Other authorities envision the possibility of "dominant battlespace knowledge." Martin Libiki expects information technologies to provide commanders with an "unprecedented level" of awareness of the conditions surrounding their decisions.[5] David Alberts speculates that technology could enable commanders to "move from a situation in which decision making takes place under 'uncertainty' or in the presence of incomplete and erroneously information, to a situation in which decisions are made with near 'perfect' information."[6]

The future concepts described by Owens and others are built on technology-intensive processes at the operational level of war in two key areas. First, they increasingly rely on analysis and synthetic representations of the battlespace to support decision makers. Second, they rely on technology to compress friendly decision cycle times in order to operate inside the adversary's decision cycle—his OODA loop.[7] Could similar technology-intensive approaches achieve the efficiencies and reliable discriminate outcomes at the strategic level of war promised by strategic precision engagement?

There is evidence to suggest otherwise: that a technology-intensive “solution” to strategic precision engagement will in fact increase the potential for strategic failure.

The “Side Effects” of Technology Intensive Approaches

In his book, *Why Things Bite Back,* Edward Tenner describes how high-tech approaches to complex problems frequently produce what he terms “revenge effects.” He cites numerous examples from the fields of industry, medicine, biology and social sciences where technology fixes increased demand in ways that offset expected efficiencies, introduced new complications to the original problem or sometimes altered the nature of problem itself, often in unexpected ways.

Consider the case of precision munitions. In improving the reliability and efficiency of force application, the demonstrated capabilities of such technologies have also amplified the significance of individual casualties and instances of collateral damage. The result has been greater demand to use precision capabilities—a consequence of what Foster and Welch describe as the imperative of precision.[8] Moreover, Author William Arkin notes that today “every weapon counts. Targets have to be meticulously chosen and the choreography of a conflict becomes ever more essential.”[9] When an improved capability increases the demands placed on that capability it is an example of what Tenner calls a redoubling or repeating effect of technology.[10]

The choreography of conflict increases the need for technological fixes to speed decision support through analysis and synthetic representations of the strategic situation. Confidence in the tools leads to even greater dependence.[11] However, Tenner found evidence that such dependence makes the decision makers susceptible to a phenomenon that psychologists call the “illusion of control”:

> the way we can easily convince ourselves, given the proper setting, that we're making things happen when in reality they are chance events. Both the beauty and the risk of computerized analysis is the concreteness it can give our plans—even when our underlying data are doubtful and our models untested or even wrong. We have seen the theatrical power of computers; in the illusion of control, we turned on ourselves to reassure ourselves that the powers we possess are indeed real.[12]

The danger, according to Tenner, is that decision makers will develop "inappropriate confidence" in the technological tools that guide their decisions.

A decade ago in their book, *War Ends and Means*, Paul Seabury and Angelo Codevilla argued a similar point in describing how the Cold War emphasis on force ratios and the mechanics of ballistic missile targeting led to unrealistic faith in the ability of systems analysis to produce meaningful strategic assessments.[13] They noted that such systems analysis created an aura of objectivity that enabled senior decision makers "to exercise power while keeping the option of claiming they are not responsible for eventual failures because they acted 'by the numbers.'"[14] Tenner finds a tendency that "the better and safer technology becomes, the more we presume human error when something goes seriously wrong. If it is not the error of the captain or the crew, it is one of the engineers or designers of equipment, or of executives and their maintenance policies."[15] While success is a result of superior technology and training, failures must be a result of mistakes by the policy makers, the intelligence analysts, the controllers or the weapon system operators rather than the underlying technological construct itself.

Tenner also found evidence that technology-intensive solutions incur a "burden of vigilance" that ultimately offsets the expected efficiencies that justified the course of action the first place.[16] He describes how banks sought to realize savings by replacing accountants with computing technologies only to find that the increased computer power

led to far greater demand than expected, and the predicted savings were eaten up by the need to ensure the software and hardware continued to perform.[17]

Strategic precision engagement demands increased vigilance in two ways. First—especially given insights from the previous chapter regarding nonlinear and complex adaptive systems—strategic precision engagement will demand increased "quality control" over the technologies and processes of intelligence collection, analysis, planning and execution process to avoid perturbations in the form of foul-ups, glitches, and other mistakes. A second burden of vigilance is the increased need to "protect" the technological infrastructure on which strategic precision engagement depends from enemy spoofing or and even direct attack. There is plenty of evidence that at least one potential strategic competitor, China, is already focusing on ways to exploit such dependencies.[18]

Tenner's findings support arguments by Barry Watts that friction will persist in future war despite important contributions of technology.[19] Moreover, Tenner's research suggests that technological fixes to strategic precision engagement are likely to *introduce* new sources of friction that will be difficult to assess or even envision ahead of time. As the next section will explain, the resultant combination of redoubling, potential for inappropriate confidence, and demands of vigilance are especially problematic revenge effects for a concept that depends on tight control and feedback to synchronize lethal force with desired discriminate effects.

Process Coupling And System Accidents

In the 1980s organizational theorist Charles Perrow studied organizations responsible for managing complex and technology-intensive processes and concluded that some

systems were inherently prone to what he called a “system accident.” His book, *Normal Accidents*, provides detailed case studies from the nuclear power and petrochemical industries.

Perrow found it useful to classify processes according to the complexity of system interactions and the degree of coupling inherent in those interactions. He described system interactions as either linear or complex. “Linear interactions are those in expected and familiar production or maintenance sequence, and those that are quite visible even if unplanned….[c]omplex interactions are those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible.”[20]

Perrow used the term coupling to describe the degree of slack present within the system. He described loosely coupled systems as decentralized, having flexible control mechanisms and many pathways to a desired outcome.[21] Such systems can “incorporate shocks and failures and pressures for change without destabilization,” they can shift into a standby mode without seriously disrupting the ultimate outcomes, and they allow for “expedient, spur-of-the-moment buffers and redundancies…even though they were not planned ahead of time.”[22] In contrast, tightly coupled systems are highly centralized, built around inflexible procedures and extremely sensitive to perturbations.[23] Tightly coupled systems are not amenable to make-shift responses and therefore require extensive up-front planning to think of and build in buffers, redundancies and alternative courses of action to deal with contingencies.[24]

Perrow concluded that processes characterized by tightly coupled, complex interactions were prone to system accidents, which he defined as “a failure in a subsystem, or the system as a whole, that damages more than one unit and in doing so

disrupts the ongoing or future output of the system."[25] He notes that systems experience small failures all the time. Even where complex interactions are involved, small failures can be managed through built-in safety mechanisms as well as experienced and quick thinking operators.[26] However, Perrow illustrates how "two or more failures, none of them devastating in themselves in isolation, [can] come together in unexpected ways and defeat the safety devices. If the system is also tightly coupled, these failures can cascade faster than any safety device or operator can cope with them, or they can even be incomprehensible to those responsible for doing the coping."[27]

Perrow points out that complex system coupling is particularly worrisome when the underlying technologies have a high catastrophic potential, which he defines as the degree to which a system accident could "cause damage to a great many humans.[28] His most compelling case studies come from the nuclear power and petrochemical industries where the catastrophic potential is high.

Strategic Precision Engagement and Complex System Coupling

An approach that seeks technological fixes to the assumptions behind strategic precision engagement could easily contribute to the very factors that tend to produce the system accidents described by Perrow. First, technology can certainly improve direct measurements of actions and effects, but the overwhelming volume of raw data increases dependence on technology to prioritize and fuse that data: "there is only so much that any human can absorb, digest, and act upon in a given period of time."[29] More importantly, some information will remain hidden or inaccessible from *a priori* direct measurement because of the contingent nature of the underlying interactions of the black box.[30] Add to this Tenner's evidence that organizations tend to develop inappropriate confidence in

sophisticated technology "solutions," and it seems apparent that technology does not resolve, and in fact may exacerbate, an organization's inability to observe or even comprehend all the interactions involved in the system—the hallmarks of complexity.

Second, the demonstrated ability of seemingly minor interactions to generate strategic effects will create powerful incentives to tightly synchronize operations at all levels of command. Unfortunately, tighter synchronization is equivalent to increased process coupling. In such circumstances, Van Crevald explains how "a failure at any point may put the entire chain in jeopardy—when, for instance, a decision is based on an out-of-date piece of information."[31] While multiple errors can sometimes "cancel each other out" other errors will reinforce one another in a negative synergy.[32] In 1994 a combination of multiple "small" failures of command and control ultimately led to accidental shoot down of two friendly Blackhawk helicopters. Similarly, the bombing of the Chinese Embassy in Belgrade and bombing of refugees outside Dakovica, Kosovo during OPERATION ALLIED FORCE were not the result of one grossly negligent act, but of a combination of individual failures that unfortunately came together to produce a "system accident."

Third, technological fixes introduce more insidious and vexing sources of complexity and coupling. Software design expert Watts Humphrey warns that "most engineers seem to think that testing will find their defects…. [I]t is an unfortunate fact that programs will run even when they have defects. In fact, they can have a lot of defects and still pass a lot of tests. To find even a large percentage of the defects in a program, we would have to test almost all the logical paths and conditions. And to find all of the defects in even small programs, we would have to run an exhaustive test."[33] This is

especially troubling because "the seriousness of a defect does not relate to the seriousness of the mistake that caused it."[34] According to Humphrey, some of industry's most costly software defects have been the result of "trivial typing mistakes."[35] Moreover, having a crack team of software programmers and analysts on hand does not solve the problem. Tenner notes that the sheer complexity of the underlying software architecture means that "every feature that is added and every bug that is fixed adds the possibility of some new and unexpected interaction between parts of the program. A small change to solve a minor problem may create a larger one."[36]

Based on Perrow's research and the above observations, it appears that technological "fixes" tend to increase system complexity and coupling and thereby increase the overall potential for a system accident. The most dangerous revenge effect of a high-tech fix to strategic precision engagement is the false sense of strategic control it might create. What about the catastrophic potential of a strategic precision engagement accident? An accident involving lethal force clearly risks "damage to humans," both intentional and unintentional. Yet strategic precision engagement accidents have other repercussions that extend well beyond direct battlefield casualties. A system accident could generate effects that alter the strategic environment in ways that require significantly more time, resources, lives or political capital to achieve an acceptable end state or perhaps even force the abandonment of the original aims. This is not merely a problem for the politicians, and therefore outside the pure military aspects of strategic precision engagement. If, given prior knowledge of those strategic effects, a political leader might choose a different course of action, shouldn't those effects be included in an assessment of catastrophic potential? In this sense, the catastrophic potential of strategic precision

engagement lies in the ability for a system accident to disproportionately complicate the strategic environment relative to the original expectations—all consequences of using a technology-intensive, complex and tightly coupled approach to achieving strategic leverage through discriminate effects.

Summary

The goal of this chapter was to examine the potential to find technical fixes to the assumptions of strategic precision engagement. On the one hand, some experts paint an optimistic picture of a technology-enhanced battlespace of the future. On the other hand, there is evidence that the technology fixes could inject inappropriate confidence into our understanding of the cause and effect relationships of the black box. This is not an argument to spurn technology since, as Gen Charles Boyd notes, "Technology works and saves lives, on both sides."[37] However, the technology fixes needed to "steer" interactions towards discriminate outcomes will tend to increase system complexity and coupling and thereby increase the potential for a system accident. Here, a technology-intensive approach might actually work against the assumption of boundedness required under strategic precision engagement since a system accident could generate disproportionately negative strategic effects.

Notes

[1] US Department of the Air Force, *Global Vigilance Reach & Power: America's Air Force Vision 2020*, 8. This document also states "…Aerospace Operations Centers will be able to gather and fuse the full range of information, from national to tactical, in real-time, and to rapidly convert that information to knowledge and understanding—to assure decision dominance over adversaries."

[2] AFDD 1, 6.

[3] Adm William A. Owens and Ed Offely, *Lifting the Fog of War* (New York: Farrar, Straus and Giroux, 2000), 14, 119.

Notes

[4] Adm William A. Owens, "The Emerging U.S. System of Systems," in *Dominant Battlespace Knowledge* (revised edition), eds. Martin C. Libicki and Stuart E. Johnson (Washington, D.C.: National Defense University Press, 1996), n.p.; on-line, Internet, 5 October 2000, available from http://www.ndu.edu/inss/books/dbk/dbkch01.html. Adm Owens also notes "Conflict is chaotic, confusing, and messy. We will never have perfect understanding of a battlefield, our systems and weapons will never work flawlessly all the time, and the forces we ask to wage war will never do everything correctly every time. The system-of-systems does not promise perfection; it promises to reduce the fog and friction of war faced by the U.S. military and to do so sufficiently to give the United States a radically better edge in conflict over any opponent, at least so long as the United States has the system-of-systems and the opponent does not."

[5] Martin C. Libicki, "DBK and its Consequences," in *Dominant Battlespace Knowledge* (revised edition), eds. Martin C. Libicki, Martin C. and Stuart E. Johnson (Washington, D.C.: National Defense University Press, 1996), n.p.; on-line, Internet, 5 October 2000, available from http://www.ndu.edu/inss/books/dbk/dbkch03.html.

[6] David S. Alberts, "The Future of Command and Control with DBK," in *Dominant Battlespace Knowledge* (revised edition), eds. Martin C. Libicki and Stuart E. Johnson (Washington, D.C.: National Defense University Press, 1996), n.p.; on-line, Internet, 5 October 2000, available from http://www.ndu.edu/inss/books/dbk/dbkch05.html. Alberts also suggests that "Commanders would have a much greater chance of having their vision correctly implemented given the automated processing and communications support provided. …By freeing commanders from worrying about the fog of war and developing contingencies for a variety of different situations, commanders could devote more effort to thinking creatively about the best way to deal with a situation and to developing options…Commanders will be able to review proposed options both in greater detail and faster than ever before, thus further increasing the likelihood that options selected will be sufficiently well conceived to actually play out in the battle without significant alteration. However, commanders of the future will be required to have a greater understanding of technology and a greater facility to work with automated tools."

[7] John G. Roos, "Effects-Based Operations: US Air Force Chief Assesses a Decade of Transformation," *Armed Forces Journal International*, March 2001, 68.

[8] John S. Foster and Larry D. Welch, "The Evolving Battlefield," *Physics Today,* December 2000, 31

[9] Author William Arkin notes, "In a peculiar way, that is a heavy burden for a mode of warfare that has demonstrated the potential to be so much less destructive and deadly than old-style bombing, in which whole neighborhoods might be leveled to take out a bridge or a factory or a rail yard. But today, when weapons can be targeted so precisely, every weapon counts. Targets have to be meticulously chosen and the choreography of a conflict becomes ever more essential." William M. Arkin, "Smart Bombs, Dumb Targeting," *The Bulletin of the Atomic Scientists* 56, no. 3 (May/June 2000), n.p.; on-line, Internet, 24 January 2001, available from http://www.bullatomsci.org/issues/2000/mj00/mj00arkin.html.

[10] Edward Tenner, *Why Things Bite Back: Technology and the Revenge of Unintended Consequences* (New York: Alfred A. Knopf, Inc., 1996), 16.

Notes

[11] Ibid, 74.

[12] Ibid, 205.

[13] Paul Seabury and Angelo Codevilla argue, "One reason why systems analysis has become so popular in our time is that one important aspect of war in the period circa 1950-90 is rather easily predictable. Given the assumption that no defenses exist against long-range ballistic missiles, and given a certain number of missiles of known reliability, warheads with known explosive yields and targets of known location and vulnerability, predicting the results of missile strikes is mere arithmetic." Paul Seabury and Angelo Codevilla, *War: Ends and Means* (New York: Basic Books, Inc., 1990), 74.

[14] Ibid, 73.

[15] Tenner, 261.

[16] Ibid, 45.

[17] Ibid, 192, 206.

[18] For a detailed discussion, see James Perry, "Operation Allied Force: The View from Beijing," *Air Chronicles*, 20 October 2000, n.p.; on-line, Internet, 24 January 2001, available from http://www.airpower.maxwell.af.mil/airchronicles/cc/Perry.html.

[19] Barry Watts asserts that despite technological advances, "friction will probably manifest itself in other ways or in areas that we may not even be able to predict." Barry D. Watts, *Clausewitzian Friction and Future War,* Institute for National Strategic Studies McNair Paper 52 (Washington, D.C.: National Defense University Press, October 1996), 104.

[20] Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (Princeton, New Jersey: University Press, 1999), 78.

[21] Ibid, 91.

[22] Ibid, 92-93, 95.

[23] Perrow notes that "tightly coupled systems have more time-dependent processes: they cannot wait or stand by until attended to.… The sequences in tightly coupled systems are more invariant. B must follow A, because that is the only way to make the product.…not only are the specific sequences invariant, but the overall design of the process allows only one way to reach the production goal.… Tightly coupled systems have little slack. Quantities must be precise; resources cannot be substituted; …failed equipment entails a shutdown because the temporary substitution of other equipment is not possible." Perrow, 93-94.

[24] Ibid, 94.

[25] Ibid, 66.

[26] Ibid, 356-7; see also 19, 53.

[27] Ibid. William Langewiesche summarized Perrow's research this way: "His point is not that some technologies are riskier than others, which is obvious, but that the control and operation of some of the riskiest technologies require organizations so complex that serious failures are virtually guaranteed to occur. Those failures will occasionally combine in unforeseeable ways, and if they induce further failures in an operating environment of tightly interrelated processes, the failures will spin out of control, defeating all interventions. The resulting accidents are inevitable, Perrow asserts, because they emerge from the venture itself. You cannot eliminate one without killing the other."

Notes

William Langewiesche, "The Lessons of ValueJet 592," *The Atlantic Monthly,* March 1998, n.p.; on-line, Internet, 25 September 2000, available from http://www.theatlantic.com/issues/98mar/valujet1.htm.

[28] Perrow, 67.

[29] Watts, 125-6.

[30] Ibid, 126.

[31] Martin Van Crevald, *Command in War* (Cambridge, Mass.: Harvard University Press, 1985), 9.

[32] Ibid, 9.

[33] Watts S. Humphrey, "Bugs or Defects?" *Watt's New?: SEI interactive* 2, no. 1 (March 1999), n.p.; on-line, Internet, 19 October 2000, available from http://interactive.sei.cmu.edu/Columns/Watts_New/1999/March/Watts.mar99.htm.

[34] Ibid.

[35] Ibid.

[36] Tenner, 269.

[37] Lt Gen Charles G. Boyd and Lt Col Charles M. Westenhoff, "Air Power Thinking: Request Unrestricted Climb," *Airpower Journal*, Fall 1991, n.p.; on-line, Internet, 8 January 2001, available from http://www.airpower.Maxwell.af.mil/airchronicles/apj/boyd.html.

CHAPTER 6

Conclusions

> *"Failure never comes easily, but it comes especially hard when success is anticipated at little cost."*[1]
>
> –George C. Herring

Over a thousand years ago, the Greek philosopher Zeno used formal logic to deconstruct physical distance in a way that "proved" the impossibility of motion.[2] The example of Zeno's paradox cautions against claiming that the deconstruction presented in this paper has "proven" the impossibility of strategic precision engagement, despite evidence that the concept suffers from important weaknesses. However, the insights revealed through this deconstruction do argue for greater clarity and more realism in how aerospace doctrine connects tactical action to strategic effect. Specifically, doctrine needs to differentiate between technical exactness and strategic correctness; recognize that foreclosing adversary option sets is more reliable than compelling specific, predetermined behaviors; and emphasize the central role of adaptation in effects-based concepts.

Recapping the Main Issues

This paper argues that delivering desired discriminate effects at the strategic level of war rests on three necessary assumptions: the ability to define desired discriminate effects

at the strategic level of war, the ability to trace the discriminate effects back to a triggering action, and the ability to ensure the *actual* effects generated by that action are only the discriminate ones being sought. A close examination of these assumptions reveals some important conceptual weaknesses that are further amplified when the problem is examined from the perspective of nonlinear and complex adaptive systems.

In nonlinear and complex systems, overall behavior can be quite different than what might be predicted from a detailed examination of system components: strategic effects are not simply the sum of tactical and operational effects. In such systems, small perturbations can generate disproportionate effects: each interaction is potentially critical. But the contingent nature of interactions within complex human systems means that the full spectrum of strategic effects may be unknowable. Many external interactions will fall outside the military's ability to control, further complicating the prediction of strategic effects. Finally, each engagement with an adversary provides stimulus for evolution, sometimes in discontinuous ways, so that identical actions do not always produce identical effects. The intrinsic nature of perturbations and unexpected discontinuities are problematic for a concept that seeks to achieve discriminate strategic effects with reliability.

The paper also found evidence that technological "fixes" are not likely to eliminate the weaknesses inherent in the assumptions of strategic precision engagement, despite stunning advances in technological capabilities. Attempts to exercise tight control through processes that quickly recognize and respond to emergent strategic effects also increase system coupling and the potential for system accidents. Moreover, the technology that enables individual actions to affect strategic outcomes directly also

means that the impact of a system accident can be severe if not catastrophic relative to the intended strategy. This conclusion undermines the assumption that the *actual* effects generated by that action are only the discriminate ones being sought. Moreover, the paper presents evidence to doubt whether strategic precision engagement could achieve the strategic efficiencies implied by the concept. In seeking to solve the strategic problem, it is quite possible that the technological "fixes" would create inefficiencies or demands for resources in other areas of the system.

In the face of these weaknesses, precision engagement seems ill-suited as a concept for dealing with the strategic level of war. As a minimum, it can lead to inappropriate confidence in estimating the amount of time and resources that will be required to achieve a particular outcome. Even if one could somehow mitigate the potential for system accidents to result in catastrophe, the evidence suggests strategic precision engagement will not be able to achieve the reliability, effectiveness or even the efficiencies it promises. Such insights argue the need for doctrine to take a more realistic and more modest approach when relating tactical cause to strategic effect.

Realism and Technological Modesty

In studying the Allied Combined Bomber Offensive of World War II, military historian Williamson Murray concluded that the "short-fall between expectations and realities [was] so noticeable [because] airmen regarded their weapons and their doctrine as a guarantee for victory—one that they could achieve without the terrible attrition that had so marked World War I. The greatest surprise of the war turned out to be the fact that the same conditions and rules governed air war as governed the more traditional forms of combat."[3] Modern technology makes aerospace power particularly susceptible

to the sort of overconfidence that Murray describes. In *Airpower and the Cult of the Offensive,* Major John Carter argues that, "The continuing acquisition of stealth platforms and precision munitions will lead to an arsenal of weapons increasingly well-suited for offensive action. When combined with the belief that any enemy is a fragile system, susceptible to manipulation by the delivery of a small number of well-placed munitions, the trap of offensive ideology is set."[4] According to Carter, such a trap risks operational and strategic failure.[5]

Strategic precision engagement is a potential trap for aerospace power because it assumes an unrealistic congruency between technology and war. Martin Van Crevald reminds us that "technology and war operate on a logic which is not only different but actually opposed, the conceptual framework that is useful, even vital, for dealing with the one should not be allowed to interfere with the other."[6] Watts sees an inherent contradiction created by casting war as fundamentally a social phenomenon on the one hand, while attempting to reduce it to technological means on the other. Watt's arguments force us to conclude that strategic precision engagement's dependence on a reduction in the absolute level of friction makes it "a false issue that diverts attention from the real business of war."[7] In short, one way for doctrine to be more realistic is to incorporate greater technological modesty—perhaps even technological humility—when relating tactical cause to strategic effect.

Exactness Versus Correctness: The Need for Clarity

The first dose of technological modesty requires doctrine to be clear that strategic correctness is an entirely different issue than engineering exactness when it comes to aerospace precision. By failing to separate the two concepts, current doctrine

superimposes the logic of technological efficiency and one-to-one relationships between cause and effect onto what Van Crevald calls the "paradoxical" nature of war. This approach clearly conflicts with insights from the study of nonlinearity and complex systems and the counter-intuitive result that more exact actions on the input side of a strategic black box do not necessarily lead to more correct effects on the output side. Flawless execution does not necessarily produce desired, discriminate effects. And if flawless execution cannot guarantee such effects, flawed execution presents far more serious challenges: since "perturbations" can generate disproportionate effects. By blending correctness and exactness, doctrine reinforces the potential for unrealistic expectations and strategic blind spots.

Doctrine should not attempt to apply the logic of precision beyond its ability to generate and apply "brute destructive force" with efficiency and reliability.[8] The exactness of precision provides commanders with valuable options relative to time-honored principles of war, such as mass and economy of force. The exactness of precision offers what airpower historian Richard Hallion calls "clear advantages in reducing risk to attacking forces."[9] However, the exactness of precision does not obviate critical uncertainties in the transformation of tactical action into strategic effect.

Foreclosing Adversary Options

An alternative and more realistic paradigm of precision force emerges when one de-emphasizes the pursuit of discriminate strategic effects. This alternative approach emphasizes precision as a means to foreclose adversary options rather than compel specific, predetermined behaviors. For example, blowing up a bridge with a precision weapon forecloses the adversary option, at least temporarily, of relying on the continued

functioning of that bridge to exercise his strategic options. Using precision to deny options has the effect of narrowing enemy flexibility to adapt—to constrain what Watts calls "option sets in possibility space." This suggests a more appropriate paradigm for employing precision force: one which focuses less on the achievement of discriminate outcomes and focuses more on the discriminate attrition of options.

Of course, the only way to ensure that a *specific* effect will occur—that a *specific* choice will be made—is to eliminate *all* the other alternatives. This alternative paradigm promises far less than what current doctrine implies with strategic precision engagement. It is, however, far more realistic. Speaking at the Unified Aerospace Power Conference, General Clark described how "we knew exactly what it took to take out Serb petroleum production. We hit it, and when the cloud covers left we saw fuel barrels being unloaded from barges on the Danube. Obviously the Serbs could get fuel from somewhere else."[10] Clearly, there are immense challenges in determining the full range of strategic alternatives open to the adversary and we must be prepared for "surprise."

Effects-Based Adaptation

The switch in paradigms does not require the abandonment of effects-based approaches in the pursuit of greater realism and clarity. Effects-based approaches can provide important sources of strategic coherence to military operations, similar to how centers of gravity allow us to "focus our own efforts."[11] Effects-based approaches also provide a language of discourse during the targeting process, and enable decision makers conceptualize and manage operational priorities.

Yet doctrine must be clear that strategic *coherence* is not equivalent to strategic *knowledge*. Even with partial insight into the strategic black box, important underlying

system interactions and linkages will remain latent and inherently unknowable until the system is stimulated. This is an important point for operational concepts that seek to influence the adversary's *hub* of power and movement. And, even though data management systems like the Joint Targeting Toolbox have the potential to increase transparency in the targeting process, they do not provide "knowledge" any more than they substitute for the insight, judgment, subtlety, balance and finesse captured in the Clausewitzian concepts of coup d'oeil and commander genius.

As a result, effects-based approaches should place less emphasis on absolute prediction and more emphasis on flexibility, both operational and intellectual. General John Jumper's counsel "not to start anything where the only plan consists of one phase" should not be interpreted as a call to develop highly-detailed multi-phase operations plans but as a call for intellectual and operational flexibility.[12] Operational flexibility is needed since effects are not "givens" to be achieved through a predetermined sequence of target sets, and "more" does not equate to "more likely." Intellectual flexibility is needed in order to avoid a dogged, single-minded pursuit of an effect that is no longer important or even obtainable in an evolutionary system of strategic interactions.

In both cases, flexibility requires an open and continuous sharing of information and challenging of underlying strategic assumptions across all dimensions (economic, political, military, social). Flexibility requires multi-disciplinary collaboration right down to the targeting level to reduce the possibility of targeting becoming a technical or social "engineering" problem. One military expert has suggested the need to put more emphasis on socio-cultural considerations as part of the targeting process:

> The targeting you have to do yourself and it involves intelligence. But as General Jumper found out, and a crucial point, the Serbian population

> forced Milosovic to call the war off when the life of the Serbian population was made very uncomfortable. Other populations will not have that reaction. Other populations are simply used to it, are passive, they are used to being maltreated and you can then persecute and make their lives so dramatic. The question is what is the difference between the Serbs and Iraq. You cannot photograph that difference. It is a question of culture and General Eaker would have said that is the right thing. The U.S. Air Force needs a department of culture.[13]

Flexibility casts technologies in the role of stimulus and response, seeking to expose the adversary's secrets in order to apply precision force in ways that narrow his options. Flexibility requires error tolerance and avoidance of over-control. It explicitly prepares for operations beyond a priori estimates.

In the end, the language of strategic precision engagement needs a booster shot of Clausewitzian friction. Williamson Murray believes that "only the marines appear to be solidly resisting the allure of technology as the answer to all the problems of war in the next century." Murray cites the "pervasive Clausewitzian flavor" of Marine Corps doctrine and their "sense of history both as a learning tool and as a warning to those who would put too much reliance on technology."[14] Marine Corps doctrine continuously emphasizes the centrality of dynamic, human interactions in war.[15] It states that, "The occurrences of war will not unfold like clockwork. We cannot hope to impose precise, positive control over events."[16] Instead, commanders should seek to "impose a general framework of order on the disorder, to influence the general flow of action," based on their best judgment of probabilities and enemy intent, recognizing that "it is precisely those [actions] that seem improbable that often have the greatest impact on the outcome of war."[17] At the strategic level of war, boldness and decisiveness must "be tempered with an appropriate sense of balance and perspective."[18]

Hopefully, a booster shot of Clausewitzian friction would keep strategic precision engagement from obscuring a fundamental truth described by Paul Seabury and Angelo Codevilla in their book, *War: Ends and Means,*: "Anyone entering the fog [of war] is best advised to look at all things he can see and control from the perspective of the only reliable compass: the idea of victory—the attainment of the goal for which he is fighting."[19]

Conclusion

Paul Seabury and Angelo Codevilla remind us that "the fog that surrounds the outcomes of war has always tempted people to spin theories about what lies on the other side. Yet reality is always a surprise."[20] The evidence suggests that strategic precision engagement spins a theory of warfare that is unrealistic and even dangerously misleading. Strategic precision engagement requires the careful untangling of Gordian knot characterized by complex connections between tactical input, mechanisms and dynamics within the enemy and our own system, and expected effects or outcomes. Discriminate strategic effects are not an automatic consequence of aerospace precision. Such shortcomings suggest that strategic precision engagement involves too much wishful thinking to be a reliable, guiding promise for aerospace power.

Having said that, the author doubts whether purely analytical arguments will ever provide a clear demarcation between what we actually "know" to be true versus what we would "like" to be true about the connection between tactical action and strategic effect. In any case, aerospace doctrine is not science—it tends to be empirical and inductive rather than analytical and deductive and it remains in constant evolution—a "work in progress."[21] In that vein, it is hoped that the arguments presented in this paper will

motivate further debate over the relationship between technical exactness and strategic correctness, and thereby contribute positively to the evolution of aerospace doctrine. Moreover, such debate will be critical in exposing strategic blind spots and potential revenge effects of precision technologies. Unfortunately, assured efficiency and effectiveness in achieving discriminate strategic outcomes is likely to remain an alluring idea, perpetually abetted by increasingly sophisticated precision and computing technologies. In such an environment, technological humility will be a difficult pill to swallow.

Notes

[1] George C. Herring, *America's Longest War: The United States and Vietnam, 1950-1975, 3rd Ed.* (New York: McGraw-Hill, Inc., 1996), 159.

[2] Zeno noted that for an object to travel a specified distance, it must first travel half that distance, then half the remaining distance (one-fourth of the original distance), then half of that remaining distance (one-eighth the original distance) and so on, *ad infinitum*. Using this logic, he argued that moving from any point A to any point B requires an infinite sum of nonzero time intervals—i.e., an infinite amount of time—and thus concluded motion must be impossible. Clearly this result is absurd; however, it is perfectly "logical" without a more sophisticated understanding of infinity; namely, that some infinite sums can indeed converge to a finite numbers.

[3] Williamson Murray, "Reflections on the Combined Bomber Offensive," *Militärgeschichtliche Mitteilungen* 51 (1992): 73-94, 87.

[4] Major John R. Carter, *Airpower and the Cult of the Offensive*, College of Aerospace Doctrine, Research and Education Paper (Maxwell AFB, Ala.: Air University Press, October 1998), 94.

[5] Carter, 94.

[6] Van Crevald, 320.

[7] Barry D. Watts, *Clausewitzian Friction and Future War,* Institute for National Strategic Studies McNair Paper 52 (Washington, D.C.: National Defense University Press, October 1996), 132.

[8] Martin Van Crevald, *Technology and War: From 2000 B.C. to the Present* (New York: The Free Press, 1989), 315-316.

[9] Richard P. Hallion, "Precision Guided Munitions and the New Era of Warfare," *Air Power History,* Fall 1996, 8.

[10] Gen Wesley Clark, former supreme allied commander Europe and commander-in-chief, United States European Command, "21st Century Coalition Warfare – Opportunities and Concerns for Aerospace Power," keynote address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 7 February 2001.

Notes

[11] Marine Corps Doctrinal Publication (MCDP) 1, *Warfighting*, 20 June 1997, 47.

[12] Gen John P. Jumper, commander, Air Combat Command, keynote address to the Unified Aerospace Power in the New Millennium Conference, Alexandria, Va., 8 February 2001.

[13] Quoted in "Operation Allied Force: Strategy, Execution, Implications," transcript of the Eaker Colloquy on Aerospace Strategy, Requirements, and Forces, Ronald Reagan International Trade Center, Washington, D.C., 16 August 1999, n.p.; online, Internet, 6 February 2001, available from http://www.aef.org/eak16aug99.html.

[14] Williamson Murray, "Military Culture Does Matter," *Foreign Policy Research Institute WIRE* 7, no. 2 (January 1999), n.p.; on-line, Internet, 5 September 2000, available from http://www.militaryconflict.org/milita~1.htm.

[15] MCDP 1, 19.

[16] Ibid, 11.

[17] Ibid, 7, 11.

[18] Marine Corps Doctrinal Publication (MCDP) 1-1, *Strategy*, 12 November 1997, 101.

[19] Paul Seabury and Angelo Codevilla, *War: Ends and Means* (New York: Basic Books, Inc., 1990), 76.

[20] Seabury and Codevilla, 66.

[21] The publication in January 2000 of Air Warfare and recent drafts of Strategic Attack in have been opportunities to further refine and even update concepts first articulated in AFDD 1 in 1997.

Bibliography

Air Force Doctrine Document (AFDD) 1. *Air Force Basic Doctrine,* 1 September 1997. Available from http://www.doctrine.af.mil/library/doctrine/afdd1.pdf.

Air Force Doctrine Document (AFDD) 2. *Organization and Employment of Aerospace Power,* 17 February 2000. Available from http://www.doctrine.af.mil/.

Air Force Doctrine Document (AFDD) 2-1. *Air Warfare,* 22 January 2000. Available from http://www.doctrine.af.mil.

Air Force Doctrine Document (AFDD) 2-1.2. *Strategic Attack,* 1 January 2000 (draft). Available from http://www.doctrine.af.mil.

Alberts, David S. "The Future of Command and Control with DBK." In *Dominant Battlespace Knowledge* (revised edition). Edited by Martin C. Libicki and Stuart E. Johnson. Washington, D.C.: National Defense University Press, 1996. On-line. Internet, 5 October 2000. Available from http://www.ndu.edu/inss/books/dbk/dbkch05.html.

Allison, Graham T. *Essence of Decision: Explaining the Cuban Missile Crisis*. Boston: Little, Brown and Company, 1971.

Arkin, William M. "Smart Bombs, Dumb Targeting." *The Bulletin of the Atomic Scientists* 56, no. 3 (May/June 2000), n.p. On-line. Internet, 24 January 2001. Available from http://www.bullatomsci.org/issues/2000/mj00/mj00arkin.html.

Barry, Maj Gen John, director of strategic planning, US Air Force. Address. Unified Aerospace Power in the New Millenium Conference, Alexandria, Va., 7 February 2001. Briefing slides available on-line from http://www.aerospacepower.org/Conference Briefings/Intro – Maj Gen Barry.ppt.

Beyerchen, Alan D. "Clausewitz, Nonlinearity and the Unpredictability of War." International Security 17, no. 3 (Winter 1992): 59-90. In *Coping with the Bounds: Speculations on Nonlinearity in Military Affairs.* Edited by Thomas J. Czerwinski. Washington, D.C.: National Defense University Press, May 1998, n.p. On-line. Internet, 5 October 2000. Available from http://www.dodccrp.org/copind.htm.

Boyd, Lt Gen Charles G., and Lt Col Charles M. Westenhoff, "Air Power Thinking: Request Unrestricted Climb." *Airpower Journal,* Fall 1991, n.p. On-line. Internet, 8 January 2001. Available from http://www.airpower.Maxwell.af.mil/airchronicles/apj/boyd.html.

Carter, Major John R. *Airpower and the Cult of the Offensive.* College of Aerospace Doctrine, Research and Education Paper. Maxwell AFB, Ala.: Air University Press, October 1998. Available from http://www.au.af.mil/au/database/projects/ay1998/cadre/carter_jr.pdf.

Chief of Staff of the Air Force. "Doctrine Watch #13: Effects-Based Operations (EBO)." 30 November 2000, n.p. On-line. Internet. Available from http://www.doctrine.af.mil/DoctrineWatch/DoctrineWatch.asp?Article=13.

Clark, Gen Wesley, former supreme allied commander Europe and commander-in-chief, United States European Command. "21st Century Coalition Warfare–Opportunities and Concerns for Aerospace Power." Keynote address. Unified Aerospace Power in the New Millenium Conference, Alexandria, Va., 7 February 2001.

Clausewitz, Carl von. *On War.* Edited and translated by Michael Howard and Peter Paret. Princeton: Princeton University Press, 1976.

Czerwinski, Thomas J, ed. *Coping with the Bounds: Speculations on Nonlinearity in Military Affairs*. Washington, D.C.: National Defense University Press, May 1998, n.p. On-line. Internet, 5 October 2000. Available from http://www.dodccrp.org/copind.htm.

Czerwinski, Thomas J. and David S. Alberts eds. *Complexity, Global Politics, and National Security.* Washington, D.C.: National Defense University Press, 1997, n.p. On-line. Internet, 20 September 2000. Available from http://www.ndu.edu/inss/books/complexity/index.html.

Dupuy, Trevor. "Theory of Combat." In *Brassey's Encyclopedia of Military History and Biography.* Edited by Franklin D. Margiotta et al. Washington, D.C.: Brassey's, 1994.

Faber, Lt Col Peter. "Competing Theories of Airpower: A Language for Analysis." Paper presented at the Air and Space Power Doctrine Symposium. Maxwell AFB, Ala., 30 April 1996. On-line. Internet, 9 February 2001. Available from http://www.airpower.maxwell.af.mil/airchronicles/presentation/faber.html.

Fogelman, Gen Ronald R. "Introduction." In *Air and Space Power in the New Millenium*. Edited by Daniel Gouré and Christopher M. Szara. Washington, D.C.: Center for Strategic and International Studies, 1997.

Foster, John S. and Larry D. Welch. "The Evolving Battlefield." *Physics Today,* December 2000, 31-35.

Gleick, James. *Chaos: Making a New Science.* New York: Penguin Books, 1988.

Gunzinger, Col Mark. "Towards Flexible Theater Air Warfare Doctrine." *Air Power History*, Winter 1996, 50-57.

Hallion, Richard P. "Precision Guided Munitions and the New Era of Warfare." *Air Power History,* Fall 1996, 4-21.

Handel, Michael I. *Masters of War: Classical Strategic Thought*, *2nd Ed*. London: Frank Cass., 1996.

Hawley, General Richard E. et al. "Global Reconnaissance-Strike." *Armed Forces Journal International*, June 2000, 52-57.

Herring, George C. *America's Longest War: The United States and Vietnam, 1950-1975, 3rd Ed.* New York: McGraw-Hill, Inc., 1996.

Humphrey, Watts S. "Bugs or Defects?" *Watt's New?: SEI interactive* 2, no. 1 (March 1999), n.p. On-line. Internet, 19 October 2000. Available from http://interactive.sei.cmu.edu/Columns/Watts_New/1999/March/Watts.mar99.htm.

Iklé, Fred Charles. *Every War Must End* (revised edition). New York: Columbia University Press, 1991.

Institute for Defense Analysis. "New Perspectives on Effects-Based Operations," draft annotated briefing, Institute for Defense Analyses Joint Advanced Warfighting Project, 6 March 2001.

Jackson, Jeffrey A. "Global Attack and Precision Strike." In *Air and Space Power in the New Millenium*. Edited by Daniel Gouré and Christopher M. Szara. Washington, D.C.: Center for Strategic and International Studies, 1997.

Jervis, Robert. "Complex Systems: The Role of Interactions." In *Complexity, Global Politics and National Security*. Edited by Thomas J. Czerwinski and David S. Alberts. Washington, D.C.: National Defense University Press, 1997. On-line. Internet, 2 October 2000. Available from http://www.ndu.edu/inss/books/complexity/ch03.html.

Jumper, Gen John P., commander, Air Combat Command. Keynote address. Unified Aerospace Power in the New Millenium Conference, Alexandria, Va., 8 February 2001.

Kaplan, Lawrence F. "Air Time." *The New Republic*, 22 January 2001, n.p.; On-line. Internet, 22 January 2001, Available from http://www.tnr.com/012201/kaplan012201.html.

Kitfield, James A. "Another Look at the Air War that Was." *Air Force Magazine* 82, no. 10 (October 1999): n.p. Online. Internet. Available from http://www.afa.org/magazine/1099eaker.html.

Langewiesche, William. "The Lessons of ValueJet 592." *The Atlantic Monthly,* March 1998, n.p. On-line. Internet, 25 September 2000. Available from http://www.theatlantic.com/issues/98mar/valujet1.htm.

Libicki, Martin C. "DBK and its Consequences." In *Dominant Battlespace Knowledge* (revised edition). Edited by Martin C. Libicki and Stuart E. Johnson. Washington, D.C.: National Defense University Press, 1996. On-line. Internet, 5 October 2000. Available from http://www.ndu.edu/inss/books/dbk/dbkch03.html.

Libicki, Martin C. and Stuart E. Johnson, eds. *Dominant Battlespace Knowledge* (revised edition). Washington, D.C.: National Defense University Press, 1996, n.p. On-line, Internet, 5 October 2000. Available from http://www.ndu.edu/inss/books/dbk/dbk1.html.

Lowe, Christian. "Air Force QDR: America's New 911 Force?" *Defense Week* 22, no. 2 (8 January 2001) 1, 6-7.

Luttwak, Edward N. "Air Power in US Military Strategy." In *The Future of Airpower in the Aftermath of the Gulf War*. Edited by Richard H. Schultz Jr. Maxwell AFB, Ala.: Air University Press, July 1992.

Marine Corps Doctrinal Publication (MCDP) 1. *Warfighting*, 20 June 1997.

Marine Corps Doctrinal Publication (MCDP) 1-1. *Strategy*, 12 November 1997.

Maxfield, Robert R. "Complexity and Organization Management." In *Complexity, Global Politics and National Security*. Edited by Thomas J. Czerwinski and David S. Alberts. Washington, D.C.: National Defense University Press, 1997. On-line. Internet, 2 October 2000. Available from http://www.ndu.edu/inss/books/complexity/ch08.html.

Meilinger, Col Phillip S. "Air Strategy: Targeting for Effect." *Aerospace Power Journal*, XIII, no. 4 (Winter 1999): 48-61. On-line. Internet, 8 January 2001. Available from http://www.airpower.maxwell.af.mil/airchronicles/apj/apj99/win99/meiling.pdf.

Meilinger, Colonel Phillip. *10 Propositions Regarding Air Power.* Air Force History and Museums Program, 1995.

Merriam-Webster OnLine: Collegiate Dictionary, 2000. n.p. On-line. Internet, 10 October 2000. Available from http://www.merriam-webster.com/dictionary.htm.
Murray, Williamson. "Reflections on the Combined Bomber Offensive." *Militärgeschichtliche Mitteilungen* 51 (1992): 73-94.
Murray, Williamson. "Military Culture Does Matter." *Foreign Policy Research Institute WIRE* 7, no. 2 (January 1999), n.p. On-line. Internet, 5 September 2000. Available from http://www.militaryconflict.org/milita~1.htm.
"Operation Allied Force: Strategy, Execution, Implications." Transcript. Eaker Colloquy on Aerospace Strategy, Requirements, and Forces, Ronald Reagan International Trade Center, Washington, D.C., 16 August 1999. Online, Internet, 6 February 2001, available from http://www.aef.org/eak16aug99.html.
Owens, Adm William A and Ed Offely. *Lifting the Fog of War.* New York: Farrar, Straus and Giroux, 2000.
Owens, Adm William A. "The Emerging U.S. System of Systems." In *Dominant Battlespace Knowledge* (revised edition). Edited by Martin C. Libicki and Stuart E. Johnson. Washington, D.C.: National Defense University Press, 1996. On-line. Internet, 5 October 2000. Available from http://www.ndu.edu/inss/books/dbk/dbkch01.html.
Perrow, Charles. *Normal Accidents: Living with High-Risk Technologies*. Princeton, New Jersey: University Press, 1999.
Perry, James. "Operation Allied Force: The View from Beijing," *Air Chronicles*, 20 October 2000, n.p. On-line. Internet, 24 January 2001. Available from http://www.airpower.maxwell.af.mil/airchronicles/cc/Perry.html.
Posen, Barry R. *The Sources of Military Doctrine.* Ithaca, NY: Cornell University Press, 1984.
Roos, John G. "Effects-Based Operations: US Air Force Chief Assesses a Decade of Transformation." *Armed Forces Journal International*, March 2001, 68.
Saperstein, Alvin M. "War and Chaos." *American Scientist* 83, no. 6 (November/December 1995), n.p. On-line. Internet, 25 Spetember 2000. Available from http://www.sigmaxi.org/amsci/articles/95articles/Saperstein.html.
Seabury, Paul and Angelo Codevilla. *War: Ends and Means*. New York: Basic Books, Inc., 1990.
Tenner, Edward. *Why Things Bite Back: Technology and the Revenge of Unintended Consequences.* New York: Alfred A. Knopf, Inc., 1996.
Toffler, Alvin and Heidi. *War and Anti-War.* New York: Little, Brown and Co., 1993.
US Department of the Air Force. *Global Vigilance Reach & Power: America's Air Force Vision 2020*.
US Joint Chiefs Staff. *Joint Vision 2010: America's Military: Preparing for Tomorrow.* Washington, D.C.: US Government Printing Office, 1995. Available from http://www.dtic.mil/jv2010/jv2010.pdf.
US Joint Chiefs Staff. *Joint Vision 2020.* Washington, D.C.: US Government Printing Office, June 2000. Available from http://www.dtic.mil/jv2020/jv2020a.pdf; jv2020b.pdf.
Van Crevald, Martin. *Command in War*. Cambridge, Mass.: Harvard University Press, 1985.

Van Crevald, Martin. *Technology and War: From 2000 B.C. to the Present*. New York: The Free Press, 1989.

Watts, Barry D. *Clausewitzian Friction and Future War*. Institute for National Strategic Studies McNair Paper 52, Washington, D.C.: National Defense University Press, October 1996. Available from http://www.ndu.edu/ndu/inss/macnair/mcnair52/m52cont.html

Wright, Major General Bruce A, deputy director for information operations, Joint Chiefs of Staff. "Information Operations, Operational Level Support to the JFC." Address to the Defense Colloquium on Information Operations, 24 March 1999. On-line. Internet. Available from http://www.aef.org/symposia/wright.html.

Zinni, Gen Anthony. Former commander, US Central Command. "America's Aerospace Force – Integration Across the Joint Spectrum." Address. Unified Aerospace Power in the New Millenium Conference, Alexandria, Va., 8 February 2001.